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Report OEHL 81-40

EVALUATION OF PORTABLE, DIRECT-READING

COMBUSTIBLE GAS METERS

SEPTEMBER 1981

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

The USAF Occupational and Environmental Health Laboratory (USAF OEHL) evaluated eight direct-reading, portable combustible gas meters. The evaluation included determination of linearity of response to a calibration gas, response to several different combustible gases and vapors, including JP-4, and the instrument's capability to measure both fire safe limits (below 20% LEL) and levels of health consequence (below 5% LEL). Recommendations of combustible gas meters for specific application can be made based upon the evaluation results.

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I. INTRODUCTION

United States Air Force personnel may be exposed to a variety of hazardous atmospheres including explosive levels of gases or vapors, toxic levels of gases or vapors, or atmospheres deficient in oxygen. At the request of HQ AFLC/SGB, the USAF OEHL conducted a performance evaluation of several combustible gas meters. These meters were chosen based on the following criteria: (1) portability (weight less than 20 pounds), (2) direct concentration reading capability, and (3) rechargeable batteries as the source of power. The meters tested, manufacturers' addresses, and principles of operation, are listed in Table I.

Purpose

In February 1979, HQ AFLC/SGB requested the USAF OEHL evaluate and recommend combustible gas indicators capable of measuring concentrations below the 5% Lower Explosive Limit (LEL). In January 1980, the USAF OEHL initiated Special Project 80-30. The objectives of the project were to determine:

1. which direct-reading instruments can accurately detect concentrations below 5% of the LEL and to check the response linearity at this level, and

2. the relative response of these instruments to combustible gases and vapors other than the calibration gas, specifically JP-4.

II. DESCRIPTION OF INSTRUMENTS

A. TLV Sniffer

1. Description

The TLV Sniffer (TLV) (Figure 1) is designed to detect combustible gases and vapors in the overall range of 1 to 10,000 ppm. The TLV Sniffer samples at 2 liters/min (nominal), and is powered by six, D-size, dry-cell batteries. Although any D-cell may be used, nickle-cadmium rechargeable batteries are recommended.

2. Principles of Operation

The TLV Sniffer uses catalyst-coated resistance elements to catalytically oxidize the combustible gas. As the gas is oxidized, the heat liberated changes the resistance of the sensor in proportion to the concentration of combustible gas. Both the catalyst-coated (active) element and a reference element are incorporated in a Wheatstone Bridge circuit and produce an electrical output proportional to the difference in their resistances. Since any change in air sample temperature or humidity affects both active and reference elements equally, the electrical signal output is relatively unaffected by temperature or humidity. However, sudden changes in humidity may affect the zero reading on the 0-100 ppm scale and the instrument

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Table I

Combustible Gas Meters Evaluated

Meter	Abbreviated Name	Manufacturer	Principle of Operation
TLV Sniffer	TLV	Bacharach Instrument Co 625 Alpha Drive Pittsburgh PA 15238	Catalytic Combustion
HNU Photoionizer	HNU	HNU Systems, Inc. 30 Ossipee Road Newton Upper Falls MA 02164	Photoionization
Organic Vapor Analyzer Model OVA-128	OVA-128	Century Systems, Corp. Presently: ANALABS (Foxboro Analytical) 80 Republic Drive North Haven CT 06473	Hydrogen Flame Ionization Detector (FID)
Portable Hydrocarbon Analyzer, Model IR-711	IR-711	Infrared Industries,Inc. P.O. Box 989 Santa Barbara CA 93102	Nondispersive infrared (NDIR) absorption
Vapotester Model D-16	Vapotester	Scott Aviation 225 Erie Street Lancaster NY 14086	Catalytic Combustion
PPM/LEL GAS Indicator with Oxygen Detector Model 1314	GasTechtor	GasTech Inc. 331 Fairchild Drive Mountain View CA 94043	Catalytic Combustion/ Electrochemical reaction for oxygen

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(Continued)

Table I

Combustible Gas Meters Evaluated

Meter	Abbreviated Name	Manufacturer	Principle of Operation
Portable Gas Detector Model CGS-8LM	Gas Detector	Enmet Corporation 2308 S. Industrial Hwy Ann Arbor MI 48104	Solid State, TGS Sensor (tin dioxide bead)
Combustible Gas/ Oxygen Detector	Bio Marine 900	Bio Marine Industries Inc. 45 Great Valley Corporate Ctr Malvern PA 79355	Catalytic Combustion/ Electrochemical reaction

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FIGURE 1. PHOTOGRAPH OF THE TLV SNIFFER

should, therefore, be zeroed at approximately the relative humidity expected during use.

B. HNU Photoionizer

1. Description

The HNU Photoionizer Model PI-101 (HNU) (Figure 2) is designed to measure the concentration of organic vapors as well as several inorganic gases, including hydrogen sulfide and ammonia. The analyzer can operate either from a rechargeable battery or continuously from an AC battery charger. The instrument has three measurement ranges of 0-20, 0-200, and 0-2,000 ppm. A span potentiometer can be used to increase or decrease the amplifier gain in these three ranges.

2. Principles of Operation

The analyzer employs the principle of photoionization for detection. Photoionization is initiated by the absorption of a photon of ultraviolet radiation energetic enough to ionize a molecule (RH) by the reaction shown below:

$$RH + h\nu \rightarrow RH^+ + e^-$$

Where $h\nu$ represents a photon with an energy equal to or greater than the ionization potential of RH. The photoionization analyzer with a 10.2 eV lamp was evaluated during the test.

C. Organic Vapor Analyzer

1. Description

The Organic Vapor Analyzer, Model OVA-128 (OVA-128) (Figure 3), is designed to detect and measure toxic and hazardous organic vapors. It can also be used for qualitative analysis, using the chromatography column to separate the various components of mixtures which are common in the industrial workplace. The analyzer can operate either from a rechargeable battery or continuously from the AC battery charger. The instrument has three measurement ranges of 0-10 ppm, 0-100 ppm, and 0-1,000 ppm. A span control (Gas Select Knob) can be used to increase or decrease the gain of the instrument.

2. Principles of Operation

The instrument utilizes the principle of hydrogen flame ionization for detection and measurement of organic vapors. During the normal survey mode operation, the sample is exposed to a hydrogen flame inside the detector chamber which ionizes the organic vapors. When most organic vapors burn, they leave positively charged carbon-containing ions (cations) which are collected by a negative-collecting electrode (cathode) in the chamber. An electric field between the conductors surrounding the flame and the collecting electrode drives the cations to the cathode. A current, corresponding to the

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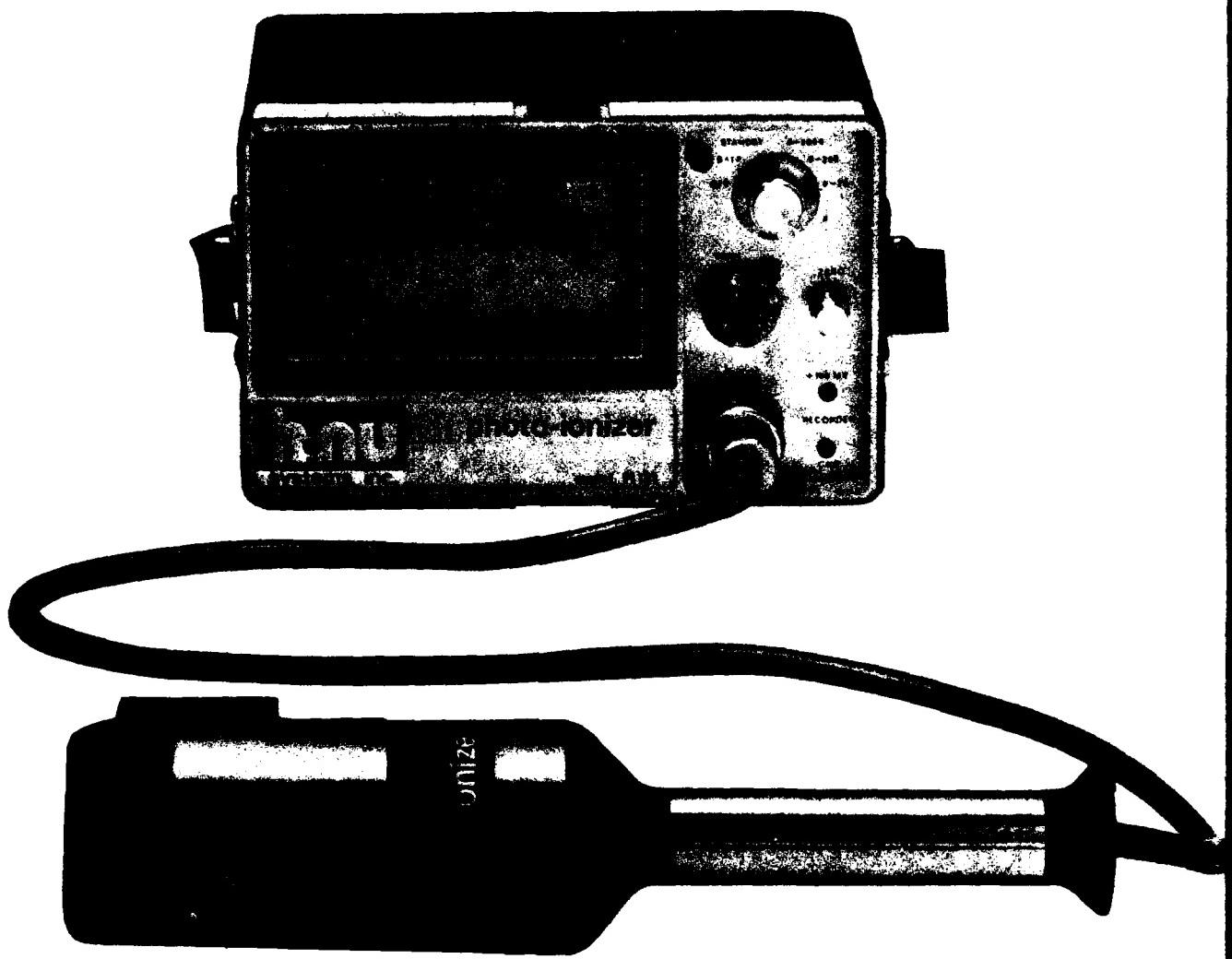
FIGURE 2. PHOTOGRAPH OF THE HNU PHOTOIONIZER

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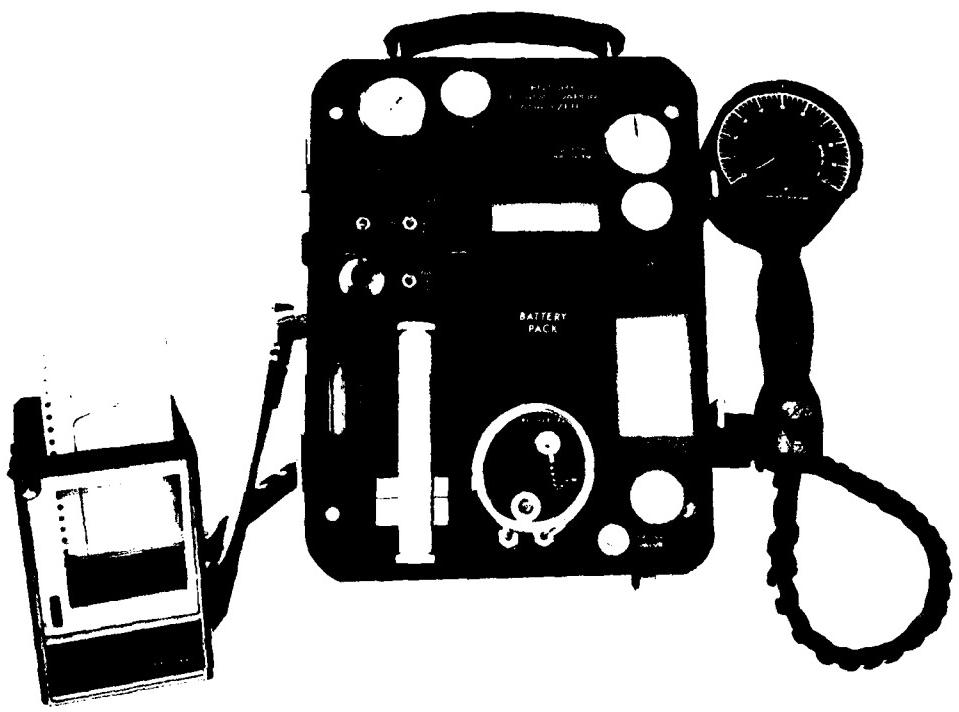
FIGURE 3. PHOTOGRAPH OF THE ORGANIC VAPOR ANALYZER

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collection rate of cations, is measured with a linear electrometer preamplifier which produces an output signal proportional to the number of molecules ionized by the flame.

D. Hydrocarbon Analyzer

1. Description

The Portable Hydrocarbon Analyzer, Model IR-711 (IR-711) (Figure 4), is designed to monitor the concentration of hydrocarbon vapors. The instrument has two measurement ranges: 0-1000 ppm, and 0-100% LEL. Its features include an internal rechargeable battery, an adjustable audio alarm, a solid-state detector, direct-reading capabilities, calibration checks, and a corrosion-resistant sample chamber.

2. Principles of Operation

The IR-711 utilizes the principles of the nondispersive infrared (NDIR) absorption technique. The analyzer features a single infrared energy source which eliminates the complex alignment problems associated with dual infrared energy sources found in some NDIR analyzers. In general, the system compares the infrared transmittance of two identical optical paths. One optical path passes through the sample of unknown gas, the other optical path passes through the reference path. The difference in optical transmittance between the paths is measured by a photon detector. The signal from the detector is then processed and used to drive the output meter as a direct measure of the concentration of the unknown gas.

E. Vapotester

The Scott Aviation's Vapotester, Model D-16 uses eight throwaway D-cell batteries. Rechargeable batteries, one of our original criteria, are not available. The device was tested because it is an improved version of the Model D-6, which is a standard issue (TA 906) combustible gas indicator (NSN 6665-00-542-1442).

1. Description

The Vapotester (Figure 5) is a portable gas detection instrument, designed to detect the presence of combustible gases and vapors in air and to give meter indications of their concentrations. The instrument has two ranges: 0 to 100% LEL and 0-10% LEL. An aspirator bulb furnishes the suction necessary for sampling.

2. Principles of Operation

The instrument utilizes the principle of catalytic combustion as discussed earlier (TLV Sniffer).   .

FIGURE 4. PHOTOGRAPH OF THE HYDROCARBON ANALYZER

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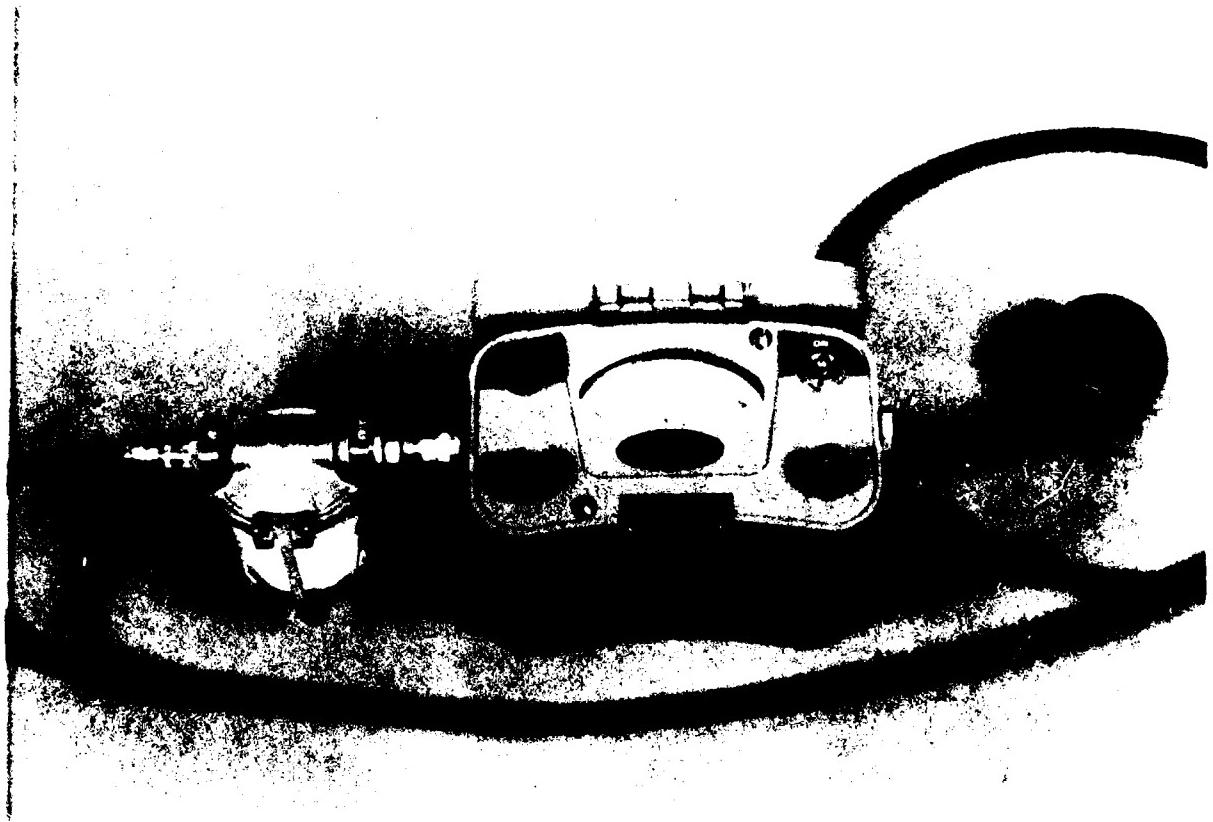
FIGURE 5. PHOTOGRAPH OF THE VAPOTESTER

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F. GasTechtor

1. Description

The GasTechtor Hydrocarbon Surveyor (Figure 6), Model 1314 (GasTechtor), is designed to detect combustible gases and oxygen deficiencies. The instrument has three measurement ranges: 0 to 500 ppm, 0 to 100% LEL and 0-25% oxygen. The sample is drawn into the instrument by means of an integral pump and continuous operation of up to six hours is assured using the built-in rechargeable battery.

2. Principles of Operation

The instrument employs the principle of catalytic combustion discussed earlier for the detection and measurement of combustible gases. Oxygen deficiency is detected by means of an electrochemical cell which generates a positive ionic current in direct proportion to the oxygen partial pressure. This current is applied to a solid-state amplifier which transmits the signal to the meter to give a readout.

G. Gas Detector

1. Description

The Enmet's Portable Gas Detector (Figure 7), Model CGS-8LM (Gas Detector), is designed to detect combustible gases and vapors in air. The instrument has two measurement ranges and was calibrated by the factory at two points: 100 ppm hexane for the lower range (toxic position) and 5% LEL hexane for the upper range (combustible position).

It is designed to clip to a worker's belt. Gas sampling is done by a convection/diffusion process and does not need a pump or squeeze bulb. Other features include audiovisual alarms and a rechargeable battery.

2. Principles of Operation

The instrument utilizes a Taguchi sensor (TGS) to detect combustible gases and vapors. It is an n-type semiconductor of sintered tin dioxide (SnO_2). When a gas with reducing properties reaches the surface, it is adsorbed and an oxidation-reduction chemical reaction occurs on the sensor surface. The result is a significant drop in electrical resistance, with a corresponding increase in conductivity. This change is measured, amplified and the output displayed on the meter.

H. Combustible Gas/O_2 Detector

1. Description

The combustible gas/O_2 detector, Bio Marine Model 900 (Figure 8), is designed to detect both combustible gases and oxygen deficiencies. The instrument has three scales: 0-100% LEL hexane, 0-40% oxygen and 0-4% methane. The samples can be obtained by diffusion at the
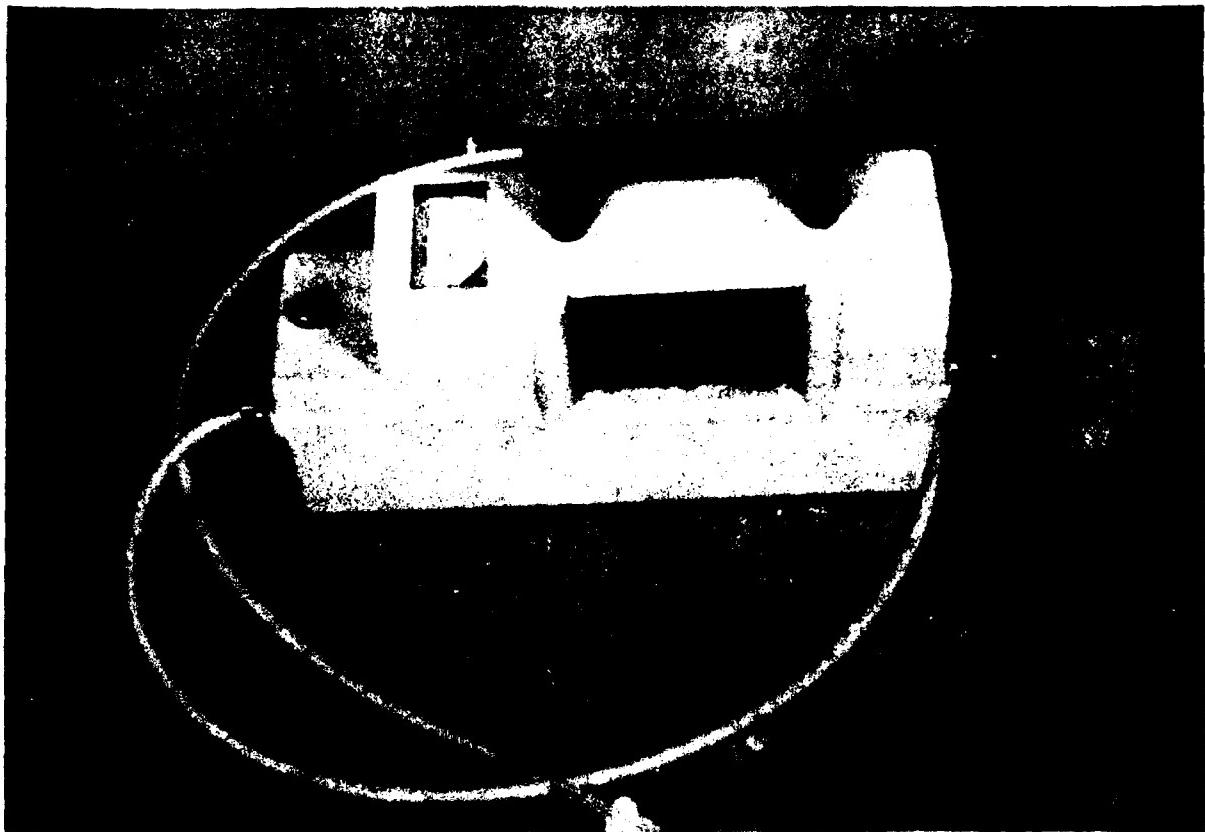
FIGURE 6. PHOTOGRAPH OF THE GASTECHTOR

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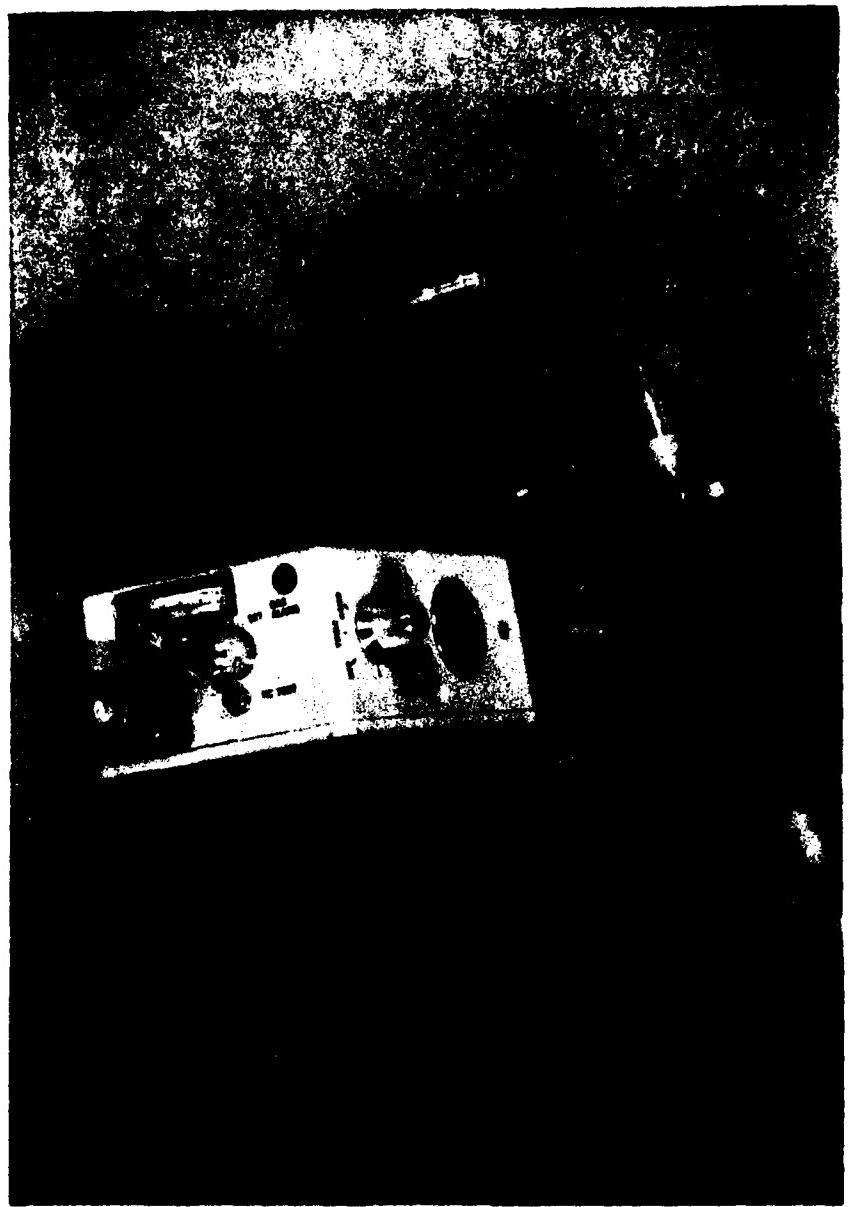
FIGURE 7. PHOTOGRAPH OF THE GAS DETECTOR

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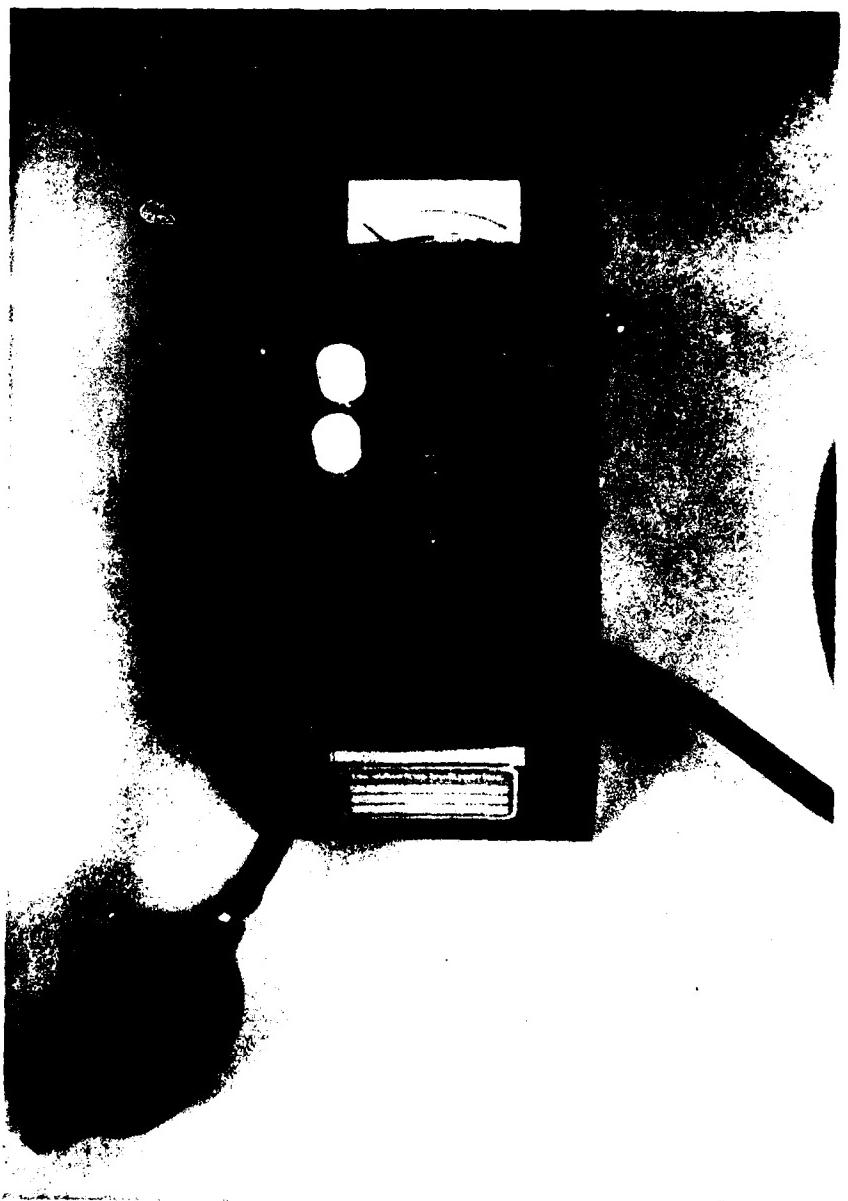
FIGURE 8. PHOTOGRAPH OF THE COMBUSTIBLE/OXYGEN DETECTOR

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instrument or remotely by using the sample draw kit. Power is supplied by rechargeable batteries.

2. Principles of Operation

The instrument employs the principle of catalytic combustion for combustible gases and elctrochemical reaction for oxygen deficiency detection.

III. EXPERIMENTAL

A. Contaminant Generation Systems

Static and dynamic calibration systems, illustrated in Figure 9, were used to generate known contaminant concentrations. Figure 10 is a photograph of the test facility area showing the arrangement of the contaminant generation systems and sampling locations.

1. Static Generation System

(a) Vapors

Concentrations of n-hexane were obtained using the static method by injecting a known liquid volume into a clean dry stream of air with simultaneous collection into a 10 liter, five-layer, snout-type, gas sampling bag (Calibrated Instrument, Inc). The volume of the gas collected in the bag was metered to achieve the desired concentrations.

Equation 1 is used to calculate the hexane liquid volume necessary to achieve the desired concentration.

$$V_L = \frac{V_G C}{\rho \times 1000} \quad \ldots \ldots \ldots \ldots \quad (1)$$

Where V_L = volume of n-hexane to be evaporated (μL)
V_G = volume of air to be collected in the bag (L)
ρ = density of n-hexane, 0.659 gm/cm^3
C = concentration of n-hexane, mg/m^3

To change a concentration from mg/m^3 to ppm at the same temperature and pressure (T and P), equation 2 is used:

$$C' = 62.32 \frac{C \ (mg/m^3) \ T \ (^{\circ}K)}{MW \ (gm/mole) \ P \ (mm \ Hg)} \quad \ldots \ldots \ldots \quad (2)$$

Where MW is the molecular weight of the liquid and C (mg/m^3) is the vapor concentration.

(b) Gases

Known concentrations of propane were obtained, using the static method by injecting a known volume of 100% propane gas with a gas-tight syringe into the metered air stream with simultaneous collection into a gas
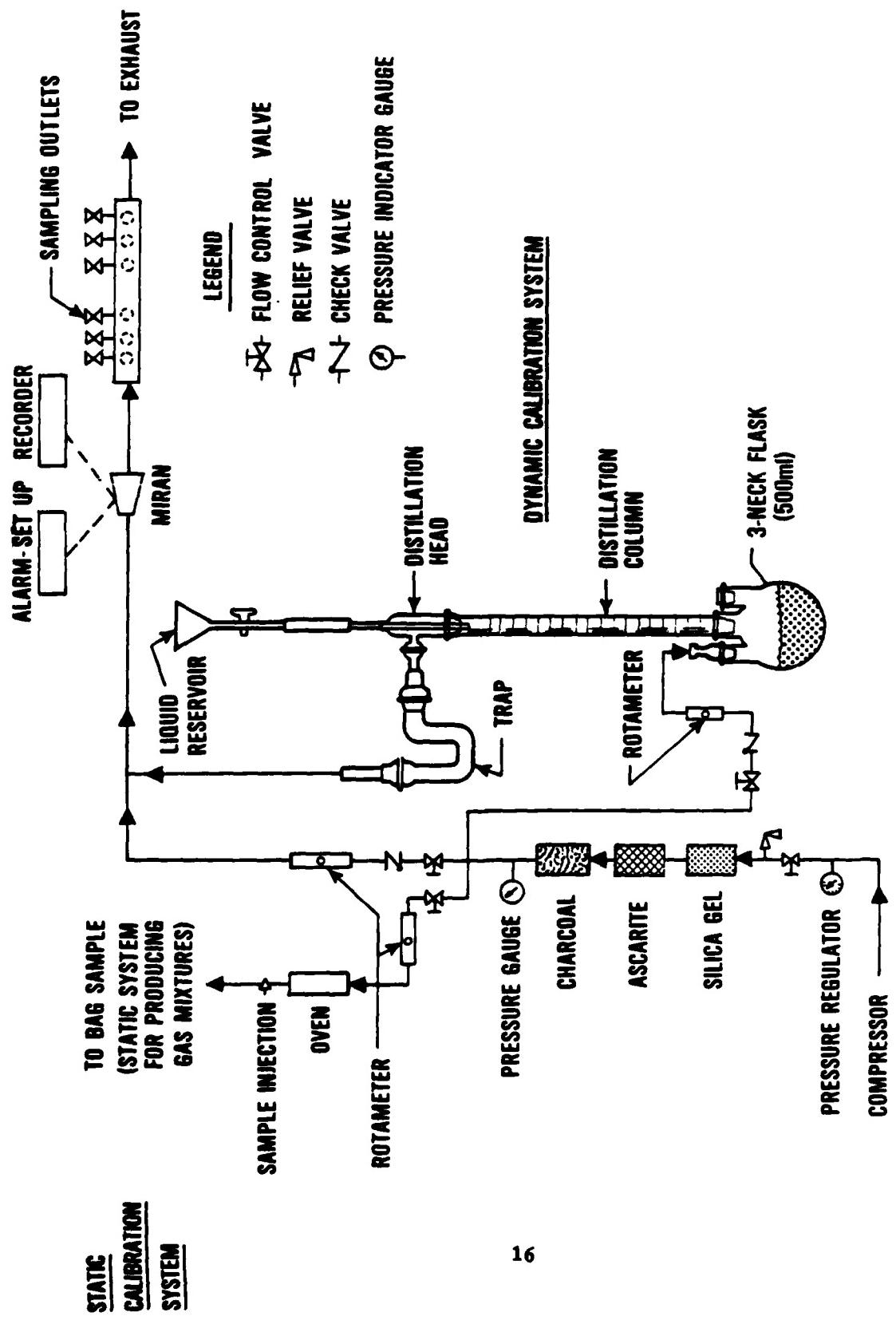
FIGURE 9. SCHEMATIC DIAGRAM FOR PRODUCING GAS MIXTURE

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FIGURE 10. PHOTOGRAPH OF THE CONTAMINANT GENERATION FACILITY

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sampling bag. Equation 3 is used to calculate the volume of propane to inject into a specific volume of air to achieve the desired concentration.

$$C'(ppm) = \frac{V_p}{V_t} \times 10^6 \quad \ldots \ldots \ldots \ldots \ldots \quad (3)$$

Where V_p = Volume of propane injected (mL)
 V_A = Volume of air (mL)
 V_t = Total volume of gas mixture collected in the bag (mL)
 $= V_p + V_A$

2. Dynamic Generation System

A concentrated vapor stream (Figure 9) was continuously generated by countercurrent volatization using a multiplate high-efficiency distillation column. A stop-cock was used to meter the continuous liquid feed to the top of the distillation column from a liquid reservoir via special 1/32" tygon tubing (suitable for gasoline, oils, and aromatic hydrocarbons). Airflow through the distillation column was controlled by a metering valve and measured by a rotameter. A check valve was used at the inlet of the rotameter to avoid any backflow during the experiment. The concentrated vapor stream was then diluted with clean dry air to the desired concentration. The dilution stream was metered with a needle valve and monitored with a calibrated rotameter. Clean dry dilution air was achieved by passing house-compressed air, regulated to 5-10 psig, through three chambers in series containing silica gel, ascarite, and activated charcoal, respectively.

The system was placed in operation by starting the liquid flow and turning on the air supply to the column after the column was completely wetted. The system was able to provide a constant concentration vapor mixture for many hours, although a certain amount of trial and error experimentation was necessary to achieve stability. The diluted vapor was passed continuously through a Miran Infrared Analyzer (Model 1A) into the sampling chamber, and exhausted into a laboratory hood. The electrical output of the Miran Infrared Analyzer was simultaneously connected to a recorder and to an alarm which was triggered if the concentration exceeded a pre-set level. Meters were tested at the chamber exit with simultaneous sampling using charcoal tubes inside the chamber. Charcoal tubes were connected to the chamber sampling points and the samples were drawn at a constant known flow of 50-100 mL/min with DuPont P-200 personnel sampling pumps.

B. Test Procedure

All instruments were charged overnight prior to testing and then zeroed according to the manufacturers' instructions after a thirty-minute warm-up period. With the exception of the IR-711, all the instruments were calibrated with n-hexane using the static generation system. The IR-711 was factory calibrated with propane for the high scale and JP-5 vapor for the low scale and recalibration with n-hexane was not accomplished. After calibration, the linearity of response to n-hexane was checked on all instruments using both static and dynamic generation systems. The

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concentrations in the dynamic system were determined by gas chromatographic and gravimetric analyses of charcoal tube samples. Time-averaged instrument scale readings were then compared with the charcoal tube results. After calibration with n-hexane, the responses of the instruments to other combustible gases and vapors, JP-4, propane, toluene and acetone, were then compared to the response of n-hexane identically generated. For example, since known JP-4 vapor concentrations could only be generated using the dynamic generation system, instrument response was compared to the response to n-hexane generated with the same dynamic system.

C. Analytical Techniques

Charcoal tube samples collected during the tests were analyzed by either gas chromatographic or both gas chromatographic and gravimetric methods. Two to three samples were usually collected for each test.

1. Gravimetric Method: Prior to each test, both ends of charcoal tubes were broken with a tube breaker, the tube ends carefully filed, the samples weighed on an analytical balance, the samples marked, and the weights recorded before the charcoal tubes were connected to the sampling ports for sample collection. The total volume of the air sampled during the tests and the final weight of the charcoal tubes were recorded. The average concentration in milligrams per cubic meter (mg/m^3) was then calculated from the air volume and weight of sample collected.

2. Gas Chromatographic Method: The samples collected during the tests were sent to the laboratory for gas chromatographic analysis. The NIOSH-approved, carbon disulfide elution method for organic solvents (P and CAM #127) was used to analyze the charcoal tubes.

IV. RESULTS AND DISCUSSION

A. Test Results

Prior to the tests, charcoal tubes were exposed to the diluent air used in the vapor generation system and analyzed by gas chromatographic and gravimetric methods. The gravimetric method indicated no significant change in weight (about $\pm$ 0.2 mg) of charcoal tubes as a result of exposure to diluent air. Gas chromatographic analyses of the exposed samples were reported as none detected. It is therefore assumed that all material observed during experimental runs is from the vapor generator and represents the true test atmosphere.

1. Gravimetric vs Gas Chromatographic Method

Charcoal tube samples were collected for n-hexane and were analyzed by gas chromatographic and gravimetric methods. The test results are shown in Table II. A fair correlation between the two methods was obtained. When comparing duplicate and triplicate samples, the gravimetric method provided a smaller standard deviation than that of the gas chromatographic method.

Gas chromatographic and gravimetric analyses of charcoal tubes for JP-4 vapors were also compared and these results are shown in Table III. Large discrepancies between the two methods were noted. This discrepancy is

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Table II

Comparison of Gravimetric Method With Gas Chromatographic
Analysis of Charcoal Tubes

Dynamic Generation of n-hexane

Sample Number	Gravimetric Method Conc. mg/m³	Avg ± Std Dev	GC Analysis Conc. mg/m³	Avg ± Std Dev	% Deviation from GC Analysis
CT-1-829	1879		1983		
CT-2-829	1933	1912 ± 29	2100	2026 ± 65	−5.6
CT-3-829	1924		1994		
CT-1-910	199		162		
CT-2-910	176	188 ± 16	160	161 ± 1	+16.8
CT-3-910	673		503		
CT-4-910	689	681 ± 11	481	492 ± 16	+38.4
CT-1-827	2643		1910		
CT-2-827	2622	2636 ± 12	1893	1921 ± 34	+37.2
CT-3-827	2644		1959		
CT-4-827	762		679		
CT-5-827	783	776 ± 12	670	673 ± 5	+15.3
CT-6-827	783		670		
CT-7-827	467		375		
CT-8-827	467	467 ± 0	377	376 ± 1	+24.2

Table III

Comparison of Gravimetric Method With Gas Chromatographi Analysis of Charcoal Tubes

Dynamic Generation of JP-4

Sample Number	Gravimetric Method Conc. mg/m³	Avg ± Std Dev	GC Analysis Conc. mg/m³	Avg ± Std Dev	% Deviation from GC Analysis
CT-1-820	1487	1510 ± 33	765	770 ± 7	+96.1
CT-2-820	1533		775		
CT-4-820	1974	2025 ± 71	748	877 ± 182	+100
CT-5-820	2075		1006		
CT-6-820	222	211 ± 16	142	130 ± 18	+62.3
CT-7-820	200		117		
CT-4-829	1596		1534		
CT-5-829	1600	1628 ± 48	1635	1558 ± 68	+4.4
CT-6-829	1681		1506		
CT-7-829	742		739		
CT-8-829	711	733 ± 19	792	774 ± 30	-5.3
CT-9-829	741		790		
CT-1-911	201	198 ± 5	101	96 ± 7	+106
CT-2-911	194		91		
CT-3-911	123	120 ± 5	61	61 ± 1	+63.5
CT-4-911	116		63		
CT-1-919	6279	6299 ± 28	6504	6486 ± 26	-2.9
CT-2-919	6318		6467		
CT-3-919	13168	13151 ± 25	12781	12879 ± 139	+2.1
CT-4-919	13133		12977		
CT-1-106	205	195 ± 15	57	60 ± 4	+225
CT-2-106	184		62		
CT-3-106	519	525 ± 8	162	164 ± 2	+220
CT-4-106	530		165		

probably due to calibration of the gas chromatograph with liquid JP-4 while analyzing JP-4 vapor. Since JP-4 vapor has a different composition than the liquid, calibration with liquid standards introduces an unknown error. The JP-4 vapor concentrations were reported in terms of mg/m^3 due to the uncertainty in the molecular weight of JP-4 vapors.

B. Evaluation Results and Discussion

The results of the portable, combustible meter evaluations are discussed in this section. All tables related to the experimental results can be found in Appendix A.

1. TLV Sniffer

a. Linearity of response to n-hexane

The instrument was calibrated by adjusting the span control to read the same concentration as the known n-hexane concentration. The results of the linearity of response tests for n-hexane, using the static generation method, are shown in Table A-I. The equations which resulted from a least-squares fit of the data are shown below:

For 0-100 Scale:	Y = 1.09X-3.94	r^2 = 0.999
0-1,000 Scale:	Y = 1.11X-9.38	r^2 = 0.999
0-10,000 Scale:	Y = 1.24X-231.1	r^2 = 0.998

Where Y = n-hexane concentration in ppm
      X = meter reading
      r^2 = correlation coefficient

The linearity of response to n-hexane immediately after calibration was excellent. All three scales respond to n-hexane fairly well. Although the zero drift is considerable on the 0-100 scale, this ultrasensitive scale is useful for locating hard-to-find gas leaks. For general use, the 0-1,000 ppm range is suggested. A concentration of 50 ppm of n-hexane is easily read on this scale and zero drift is not a problem.

The calibration stability of the instrument for the 0-1,000 scale was rechecked in three weeks and was excellent. During this period, the slope of the least-squares line changed by a maximum of 2% with a 5 ppm change in intercept.

b. Response to propane

The response of the instrument to propane was determined on the 0-10,000 scale after calibration with n-hexane. Duplicate samples for each concentration were tested and an average instrument meter reading was used. The results are shown in Table A-II and graphically presented in Figure 11. The data described by this least-squares line is:

Y = 1.17X+165.4 r^2 = 1.000

Where Y = propane concentration in ppm
      X = meter reading

TLV SNIFFER

SCALE:0-10,000

METHOD OF VAPOR/GAS GENERATION:STATIC
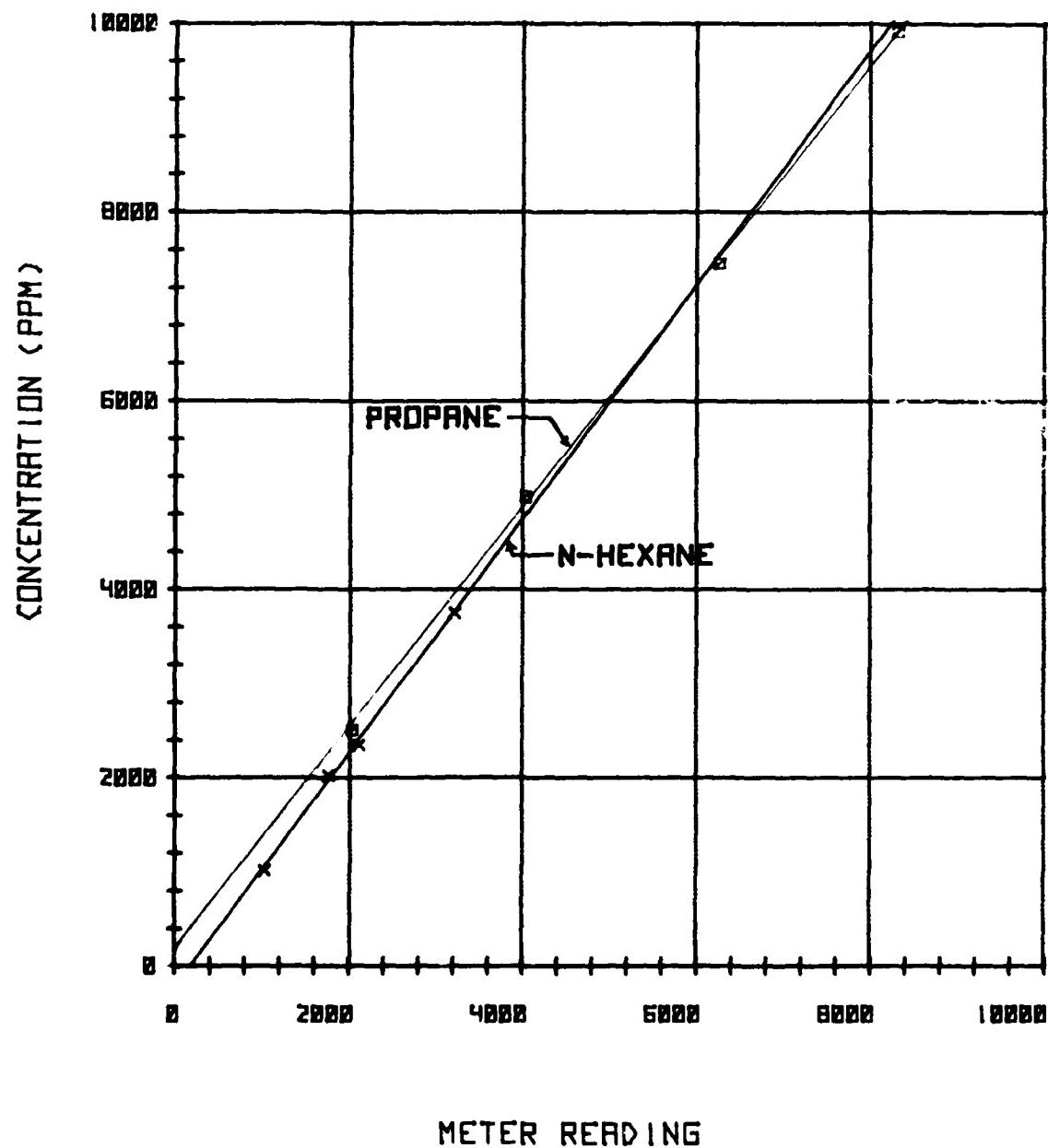
N-HEXANE:X   PROPANE:0


FIGURE II. TLV SNIFFER RESPONSE TO N-HEXANE & PROPANE

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c. Response to JP-4 vapor

The response to JP-4 vapor was also determined and the results of these tests are shown in Table A-III in mg/m³ units. The response of JP-4 vapor and n-hexane, generated by the dynamic method, on the 0-1,000 scale are shown in Figure 12. The equations of the best-fit lines for n-hexane and JP-4 vapor, using gravimetric analysis to determine the chamber concentration, are shown below:

$$Y_1 = 4.11X - 176.6 \qquad r^2 = 0.992 \text{ for n-hexane}$$
$$Y_2 = 4.18X - 210.6 \qquad r^2 = 0.986 \text{ for JP-4 vapor}$$

Where Y_1 = n-hexane concentration in mg/m³
       Y_2 = JP-4 vapor concentration in mg/m³
       X = meter reading in ppm scale

The instrument's response to JP-4 vapor on the 0-1,000 ppm scale is fairly linear and is similar to the response to n-hexane. Therefore, the relative response curve to n-hexane will provide a reasonable estimate of the actual JP-4 vapor concentration in terms of mg/m³.

d. General performance

The general performance of the TLV Sniffer was good. The instrument is fully portable (weighs only 5-1/2 lbs) with internal rechargeable batteries suitable for a minimum of 8 hours operation. A recorder (range 0-100 mv) can be connected for recording the variations in combustible gas levels during continuous operation. The instrument is easy to operate and all controls and adjustments are easily accessible and clearly labeled. The span and zero adjustments are independent and easy to use. An audible alarm can be set to respond to any desired degree of pointer deflection across the meter dial. A 100 ohm impedence earphone set may be attached to the earphone jack plug wherever noise in an area to be tested could mask the audible signal from the speaker.

2. HNU Photoionizer

a. Linearity of response to n-hexane

The instrument was calibrated on the 0-200 ppm scale by adjusting the span control (gain setting) to read the same as the known n-hexane concentration. A gain setting of 0.30 was determined for the direct-reading capability (0-200 ppm scale) for n-hexane. A slight change in gain setting (0.35) was noted for the 0-2,000 ppm scale. The results of the linearity of response tests for n-hexane, using the static generation method, are shown in Table A-IV. The equations which resulted from a least-squares fit of the data are shown below:

For 0-200 scale: $Y = 1.02X - 4.3 \qquad r^2 = 0.999$
    0-2,000 scale: $Y = 1.63X - 123.0 \qquad r^2 = 0.981$

Where Y = n hexane concentration in ppm
    X = meter reading
 r^2 = correlation coefficient

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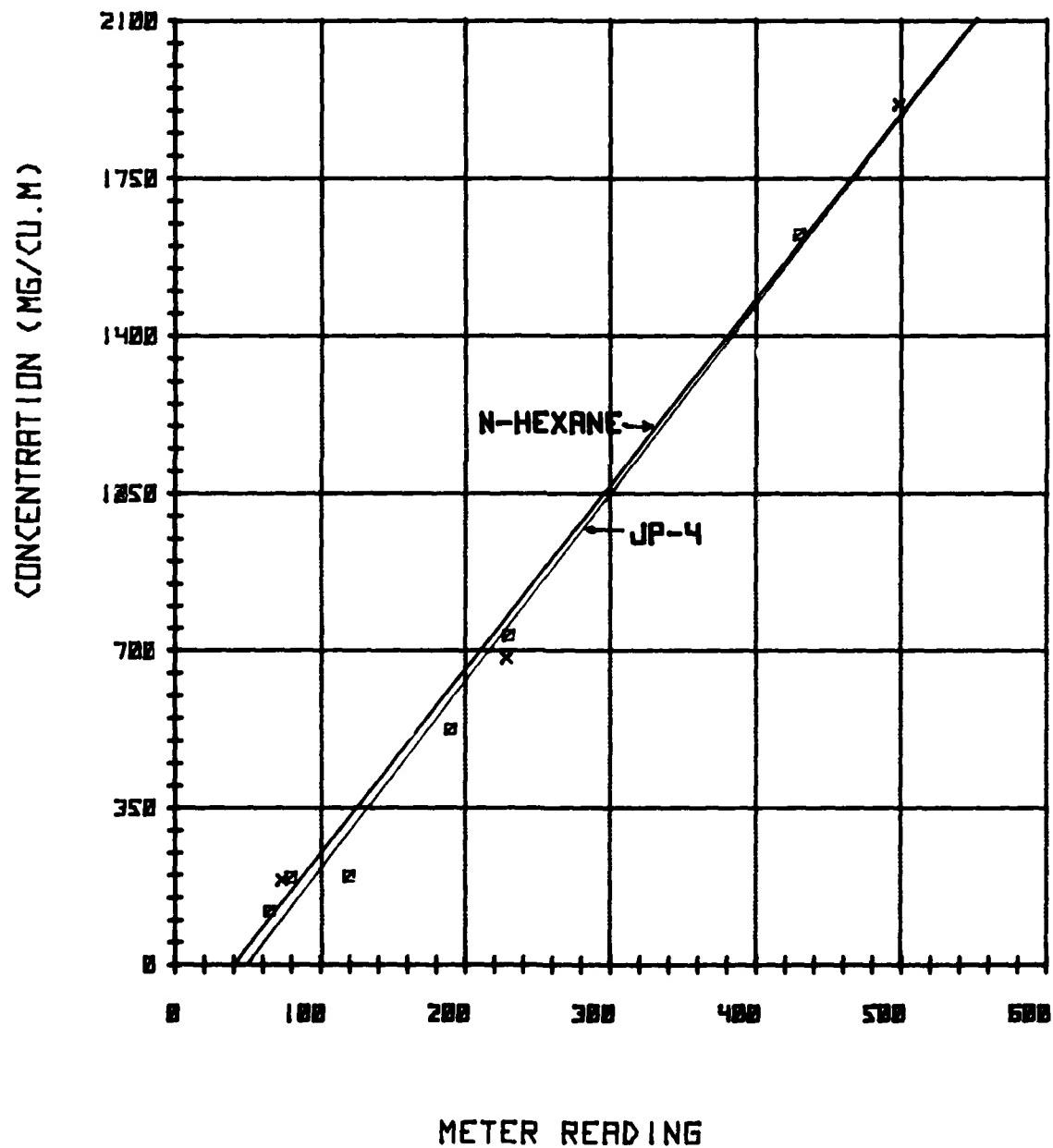
FIGURE 12. TLV SNIFFER RESPONSE TO N-HEXANE & JP-4 VAPOR

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The linearity of response to n-hexane with a 10.2 eV UV source immediately after calibration was excellent for the 0-200 ppm scale, but poor on the 0-2,000 ppm scale. For the 0-2,000 ppm scale, the meter reading is linear up to 300 ppm but indicates a lower response at higher concentration.

The calibration stability of the instrument for the 0-200 ppm scale was rechecked in three weeks and was poor. The slope of the least-squares line changed by a maximum of 22% with a 1 ppm change in intercept during this period.

b. Response to JP-4 vapor

The response of the instrument to JP-4 vapor was determined on the 0-2,000 scale after calibration with n-hexane. The results of these tests are shown in Table A-V, in units of mg/m³. The response of JP-4 vapor and n-hexane generated by the dynamic method are shown in Figure 13. The equations of the best-fit lines for n-hexane and JP-4 vapor, using gravimetric analysis to determine the chamber concentration, are shown below:

$$Y_1 = 5.54X - 245.0 \qquad r^2 = 0.969$$
$$Y_2 = 2.30X - 69.2 \qquad r^2 = 0.991$$

Where Y_1 = n-hexane concentration mg/m³
Y_2 = JP-4 vapor concentration in mg/m³
X = meter reading in ppm scale

The instrument's response to JP-4 vapor and n-hexane are different. Therefore, the relative response curve to n-hexane will not provide a reasonable estimate of the actual JP-4 vapor concentration in terms of mg/m³.

c. General performance

The instrument is not suitable to identify or quantify components in mixtures of gases or vapors such as JP-4. However, it can be used for a single gas or vapor if properly calibrated using a proper light source. The meter is fully portable and can be operated either from a rechargeable battery for a minimum of 8 hours or continuously from the AC battery charger. The meter is easy to operate and all controls and adjustments are easily accessible. A recorder (range 0-100 mv) can be connected to the meter for continuous monitoring. The span and zero adjustments are independent and easy to use.

3. Organic Vapor Analyzer (OVA-128)

a. Linearity of response to n-hexane

The instrument was calibrated on the 0-100 ppm scale by adjusting the span control (Gas Select Knob) to read the same as the known n-hexane concentration. The Gas Select Knob was found adequate for the direct reading of n-hexane when set to 534. The results of the linearity of response tests for n-hexane, using the static generation method, are shown in

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HNU PHOTOIONIZER

SCALE:0-2,000

METHOD OF GENERATION:DYNAMIC

N-HEXANE:X JP-4 VAPOR:0
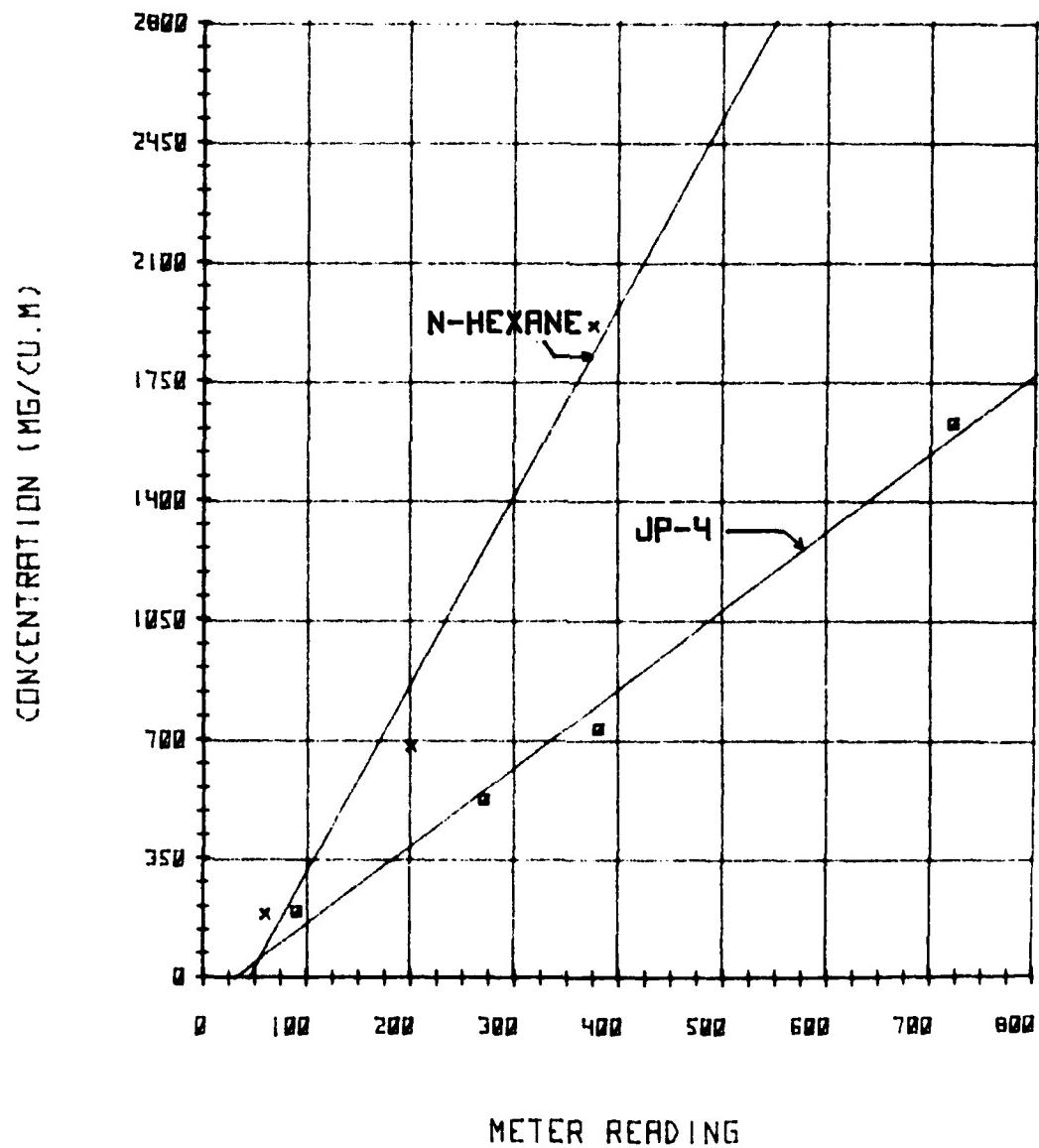
FIGURE 13. HNU PHOTOIONIZER RESPONSE TO N-HEXANE & JP-4 VAPOR

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Table A-VI. The equations which resulted from a least-squares fit of the data are shown below.

For 0-100 Scale: $Y = 1.01X - 2.42$ $r^2 = 0.999$
   0-1,000 Scale: $Y = 0.705X + 46.7$ $r^2 = 0.999$

Where Y = n-hexane concentration in ppm
    X = meter reading
    r^2 = correlation coefficient

The linearity of response to n-hexane immediately after calibration was excellent for the 0-100 ppm scale and fair on the 0-1,000 ppm scale. For the 0-1,000 ppm scale, the meter reading appears to be linear below 300 ppm and indictes a higher response at higher concentration.

The calibration stability of the instrument for the 0-1,000 ppm scale was rechecked in three weeks and was good. During this period, the slope of the least-squares line changed by a maximum of 5% with a 3 ppm change in intercept.

b. Response to JP-4 vapor

The response of the instrument to JP-4 vapor was determined on the 0-1,000 scale after calibration with n-hexane. The results of these tests are shown in Table A-VII in mg/m³ units. The response to JP-4 vapor and n-hexane generated by the dynamic method are shown in Figure 14. The equations of the best-fit lines for n-hexane and JP-4 vapor, using gravimetric analysis of charcoal tube samples to determine the chamber concentration, are shown below:

$Y_1 = 2.28 X + 77.3$ $r^2 = 0.999$
$Y_2 = 2.45 X + 52.6$ $r^2 = 0.992$

Where Y_1 = n-hexane concentration in mg/m³
    Y_2 = JP-4 vapor concentration in mg/m³
    X = meter reading in ppm scale

The instrument's response to JP-4 vapor on the 0-1,000 ppm scale is fairly linear and is similar to the response to n-hexane. Therefore, the relative response curve to n-hexane will provide a reasonable estimate of the actual JP-4 vapor concentration in terms of mg/m³.

c. General Performance

The general performance of the meter was good. It is completely portable, it provides a continuous readout of total organic vapors and it has capabilities for on-the-spot chromatographic analysis. It can be operated either from a rechargeable battery or continuously from the AC battery charger. The meter is easy to operate and all controls and adjustments are easily accessible. An audible alarm can be pre-set to the desired level with an option to use earphones where necessary.

OVA-128
SCALE:0-1,000
METHOD OF VAPOR GEN:DYNAMIC
N-HEXANE:X JP-4 VAPOR:0
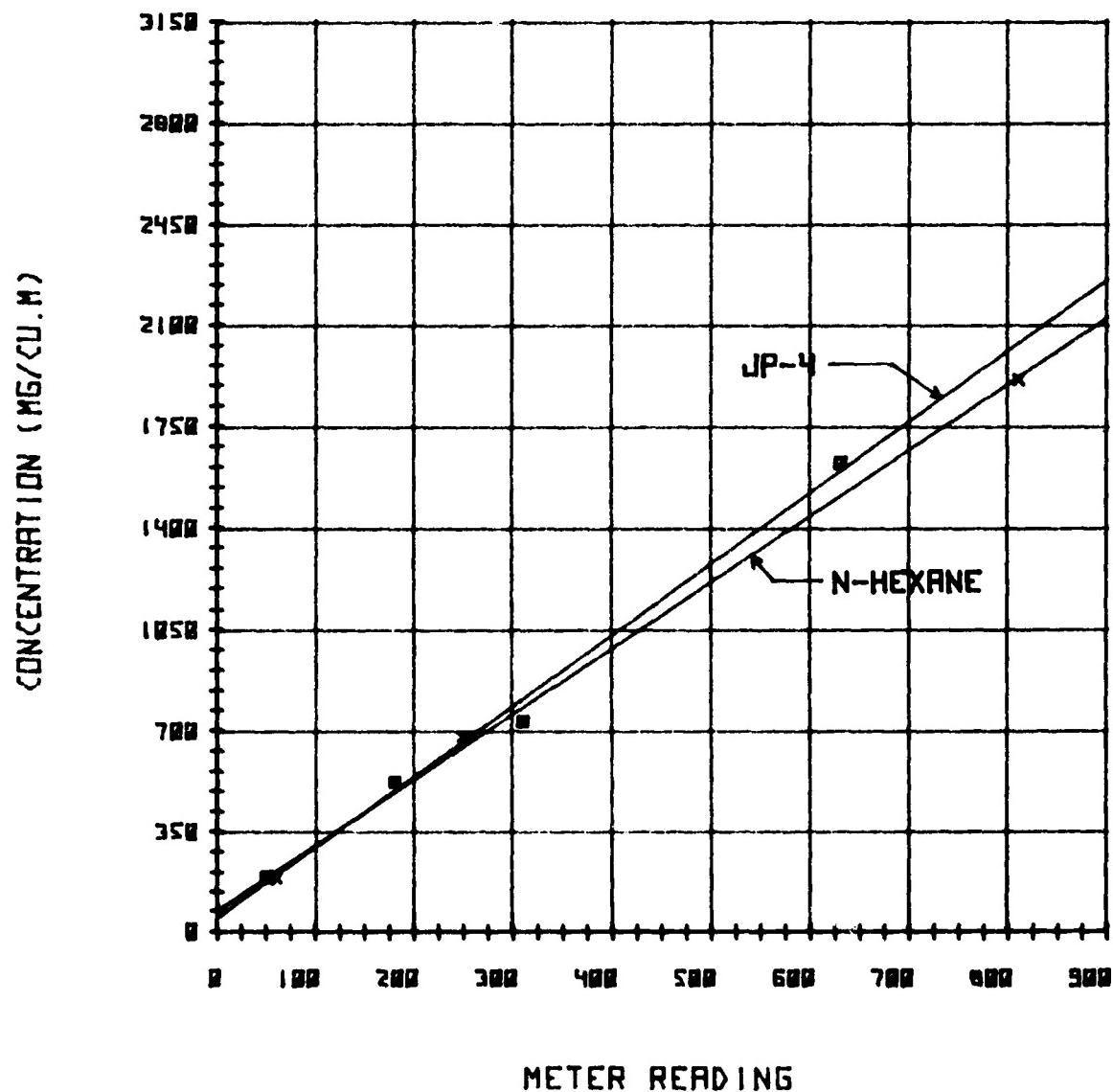
FIGURE 14. OVA-128 RESPONSE TO N-HEXANE & JP-4 VAPOR

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4. Hydrocarbon Analyzer (IR-711)

a. Linearity of response to JP-5 vapor

Due to its low volatility, the generation of high
concentrations of JP-5 vapor is difficult with the existing generation system,
and only two tests at lower concentrations were performed to check the
manufacturer's calibration on the 0-1,000 ppm scale. The concentrations of
the samples collected during the tests are expressed in terms of mg/m^3 due to
the uncertainty of the molecular weight of JP-5 vapor. True comparison was,
therefore, not possible as the meter scale reads in ppm. However, assuming
the average molecular weight of JP-5 liquid to be 169 (Reference 1),
conversion to ppm units of JP-5 vapor were calculated as:

$$ppm = \frac{mg}{m^3} \times \frac{24.45}{169}$$

The test results and the calculated concentrations in ppm
are shown in Table A-VIII. In both cases larger fluctuations in meter
readings were noted below 100 ppm.

b. Linearity of response to propane

The manufacturer's calibration of propane on the 0-100% LEL
scale was also checked and the results are shown in Table A-IX. The equation
of the best-fit line resulting from the data is shown below:

$$Y = 0.914 \, X + 1.55 \qquad r^2 = 0.997$$

Where Y = propane concentration in %LEL
  X = meter reading
  r^2 = correlation coefficient

The linearity of response to propane for the 0-100% LEL
scale was excellent.

c. Response to n-hexane, JP-4 vapor and toluene

The responses to JP-4 vapor and n-hexane on the 0-1,000 ppm
scale were compared. The test results are shown in Table A-X and graphically
presented in Figure 15. The equations of the best-fit lines for n-hexane and
JP-4 vapor, generated by the dynamic method and using gravimetric analysis to
determine the chamber concentration, are shown below:

$$Y_1 = 5.81 \, X + 9.36 \qquad r^2 = 0.975$$
$$Y_2 = 5.63 \, X - 222.0 \qquad r^2 = 0.917$$

Where Y_1 = n-hexane concentration in mg/m^3
  Y_2 = JP-4 vapor concentration in mg/m^3
  X = meter reading in ppm scale

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IR-711
SCALE:0-1,000
METHOD OF VAPOR GEN:DYNAMIC
N-HEXANE:X   JP-4 VAPOR:0
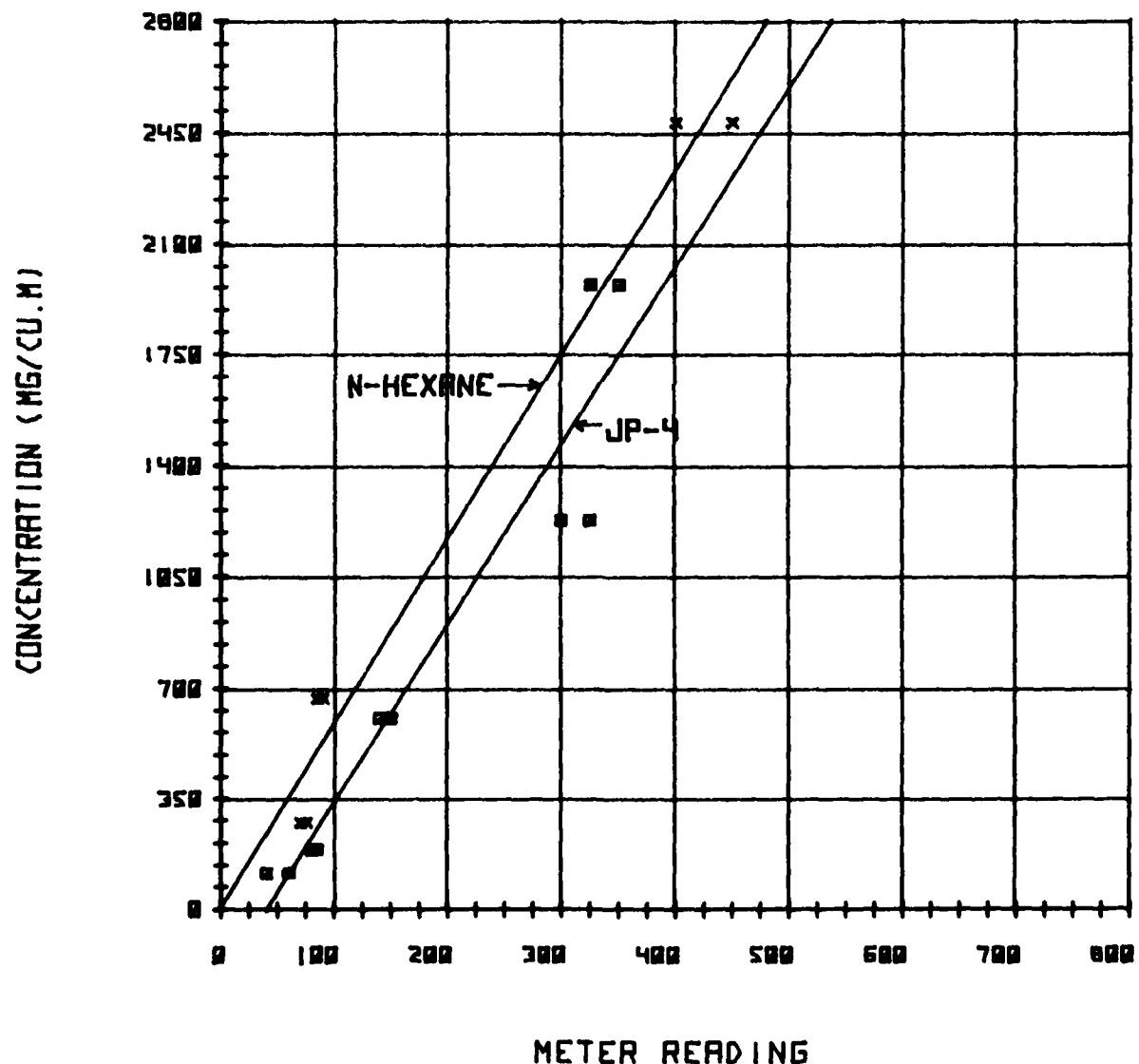
FIGURE 15. IR-711 RESPONSE TO N-HEXANE & JP-4 VAPOR

The instrument's response to n-hexane and JP-4 vapor at low concentrations was poor. The major drawback to the instrument is that the calibration for the ppm scale is fixed. Additionally, the sensitivity of the meter below 100 ppm is not very good and a high zero drift (about ±25 ppm) was also noted on the ppm scale.

The response to n-hexane and toluene on the 0-100% LEL scale was checked using the static generation system. Experimental data are shown in Table A-XI. Figure 16 shows the response of IR-711 to propane, n-hexane and toluene on the 0-100% LEL scale. The response was linear on this scale and was the same for both propane and n-hexane. The instrument is not designed to respond to aromatic compounds, and its response to toluene was poor as expected. The equation of the best-fit line for n-hexane using the static generation method is shown below:

$$Y = 0.934 \; X + 0.274 \qquad r^2 = 0.996$$

Where Y = n-hexane concentration in % LEL
      X = meter reading

An LEL of 5% and above can be detected with an error of ±25% of the reading and the zero drift on the 0-100% LEL scale is small (about 2.5% of full scale) compared to the ±25 ppm drift observed on the 0-1000 ppm scale.

d. General performance

The general performance was good for the % LEL scale, but poor for the ppm scale. Due to its poor sensitivity on the ppm scale, the meter may not be suitable for measuring concentrations of gases and vapors at concentrations near the permissible exposure limits (PELs). The meter is fully portable and can be operated from a rechargeable battery. It is easy to operate and all controls and adjustments are easily accessible. There is a problem in adjusting the zero-position. It was noted after zeroing the instrument while holding the probe with the hand, that placing the probe on the table cause deviation to the instrument's zero. An audible alarm can be set between 0 and 50% LEL. Other observed performance criteria are tabulated in section V.

5. Vapotester

a. Linearity of response to n-hexane

The manufacturer's calibrations of n-hexane on the 0-10% LEL and the 0-100% LEL scales were checked and the test results are shown in Table A-XII. The equations which resulted from a least-squares fit of the data are shown below:

For 0-10% LEL Scale: Y = 1.17X+0.007 r^2 = 0.999
    0-100% LEL Scale: Y = 1.25X-0.193 r^2 = 0.999

IR-711
SCALE:0-100%LEL
METHOD OF VAP/GAS GEN:STATIC
N-HEXANE:X PROPANE:0 TOLUENE:*
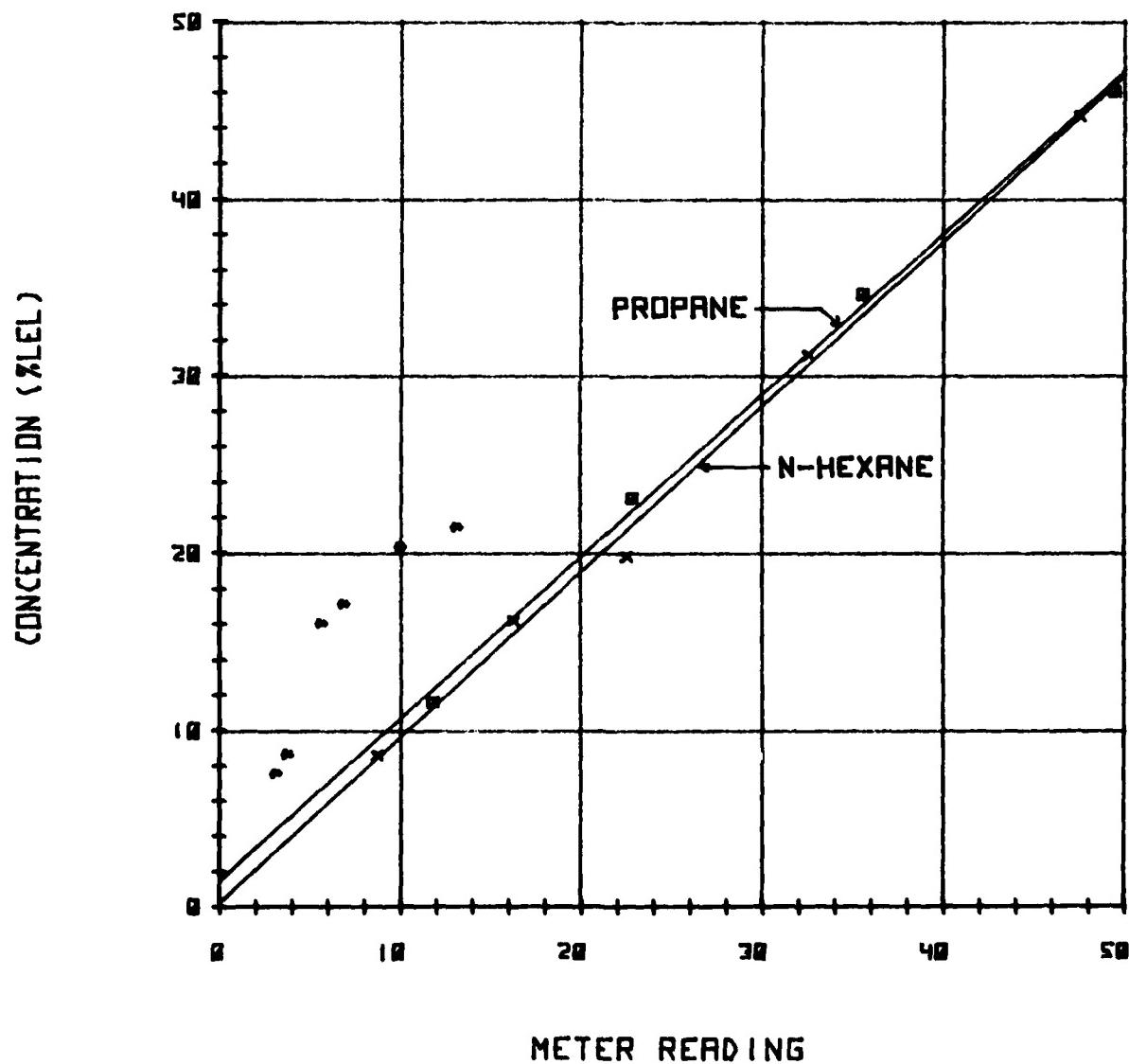
FIGURE 16. IR-711 RESPONSE TO N-HEXANE, PROPANE & TOLUENE

Where Y = n-hexane concentration in % LEL
     X = meter reading
     r^2 = correlation coefficient

The linearity of response to n-hexane was excellent for both scales. The calibration stability of the instrument for the 0-10% LEL and 0-100% LEL scales was rechecked in six weeks and was fair. The slopes of the least-squares lines changed by 13% on the 0-10% LEL scale and 4% on the 0-100% LEL scale during this period.

b. Response to acetone

The response of the instrument to acetone was compared with the response to n-hexane. The results are shown in Table A-XIII and graphically presented in Figures 17A and 17B. The equations of the best-fit lines for acetone are shown below:

For 0-10% LEL Scale: Y = 1.01X-0.085 r^2 = 0.999
    0-100% LEL Scale: Y = 0.95X-0.019 r^2 = 0.999

Where Y = acetone concentration in % LEL
     X = meter reading

The instrument's response to acetone was noted to be 14% higher on the 0-10% LEL scale and 24% higher on the 0-100% LEL scale, when compared with its response to n-hexane.

c. Response to JP-4 vapor

The response to JP-4 vapor was determined and the test results are shown in Table A-XIV. These results were compared to the charcoal tube results analyzed by the gas chromatographic method. The analytical laboratory now calibrates the gas chromatograph with n-hexane (rather than liquid JP-4) and the concentration of JP-4 vapors is reported in mg/m^3 as n-hexane. The responses of JP-4 vapor and n-hexane on the 0-10% LEL scale, generated by the dynamic method, are shown in Figure 18. The equations of the best-fit lines for n-hexane and JP-4 vapor, are shown below:

Y_1 = 373X+2.79 r^2 = 0.992
Y_2 = 379X+17.1 r^2 = 0.979

Where Y_1 = n-hexane concentration in mg/m^3
     Y_2 = JP-4 vapor concentration in mg/m^3 (as n-hexane)
     X = meter reading in % LEL scale

The meter response to JP-4 vapor on the 0-10% LEL scale is fairly linear and is similar to the response to n-hexane. Therefore, the relative response curve to n-hexane will provide a reasonable estimate of the actual JP-4 vapor concentration in terms of mg/m^3 as n-hexane.

VAPOTESTER
SCALE:0-10%LEL
METHOD OF VAPOR GEN:STATIC
N-HEXANE:X   ACETONE:0
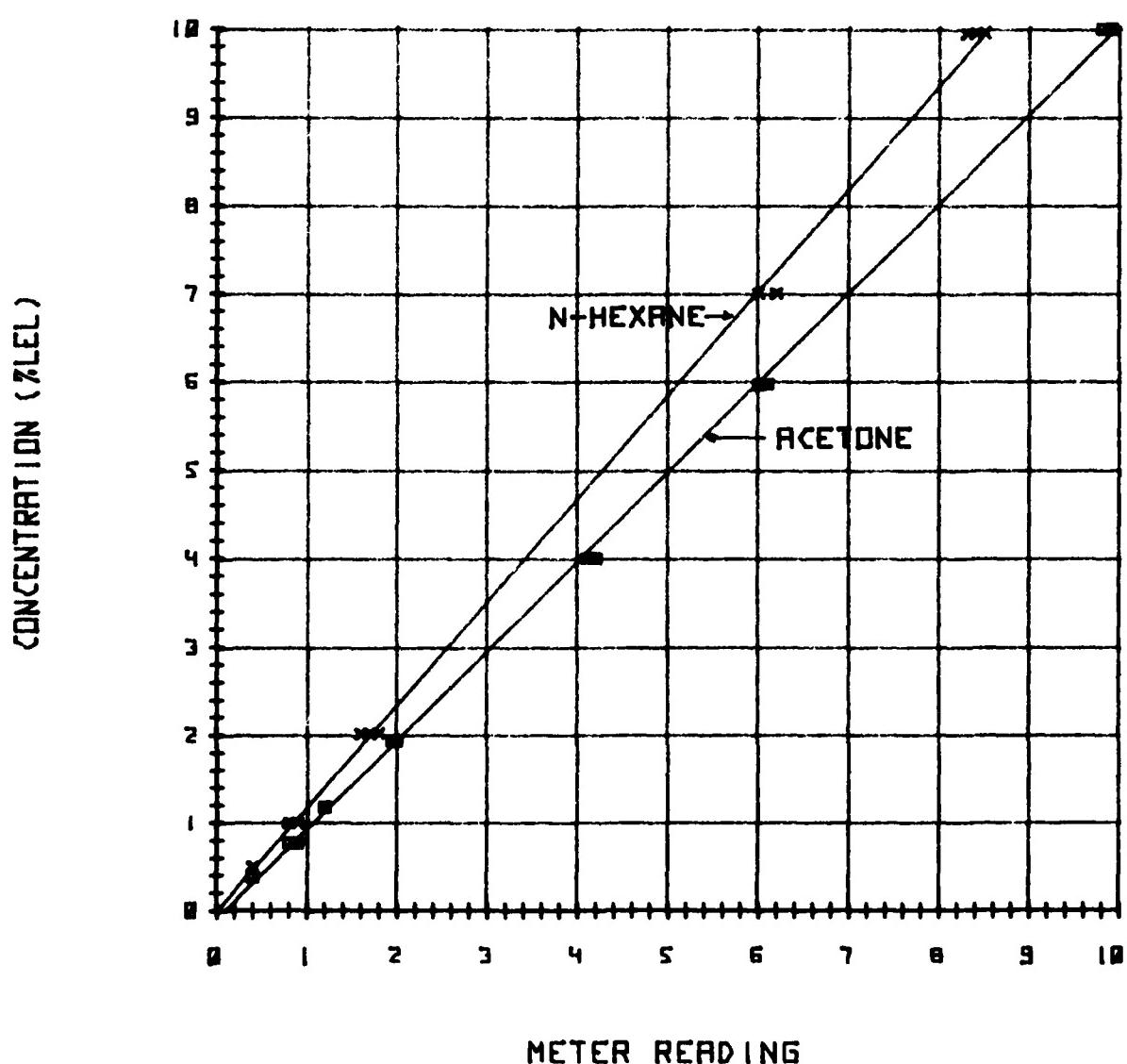
FIGURE 17A.VAPOTESTER RESPONSE TO ACETONE & N-HEXANE

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VAPOTESTER
SCALE:0-100%LEL
METHOD OF VAPOR GEN:STATIC
N-HEXANE:X ACETONE:0
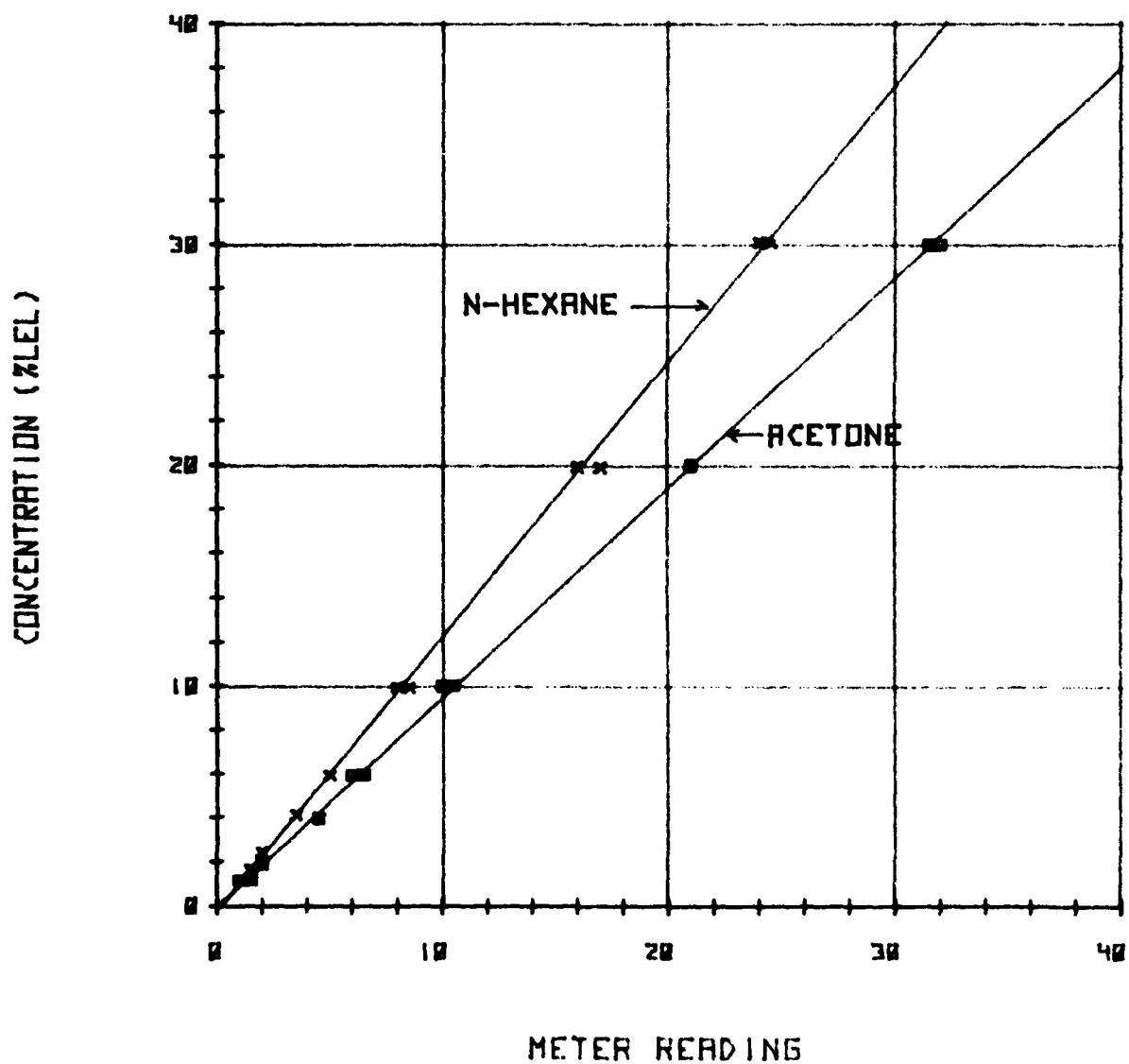
FIGURE 17B. VAPOTESTER RESPONSE TO ACETONE & N-HEXANE

36
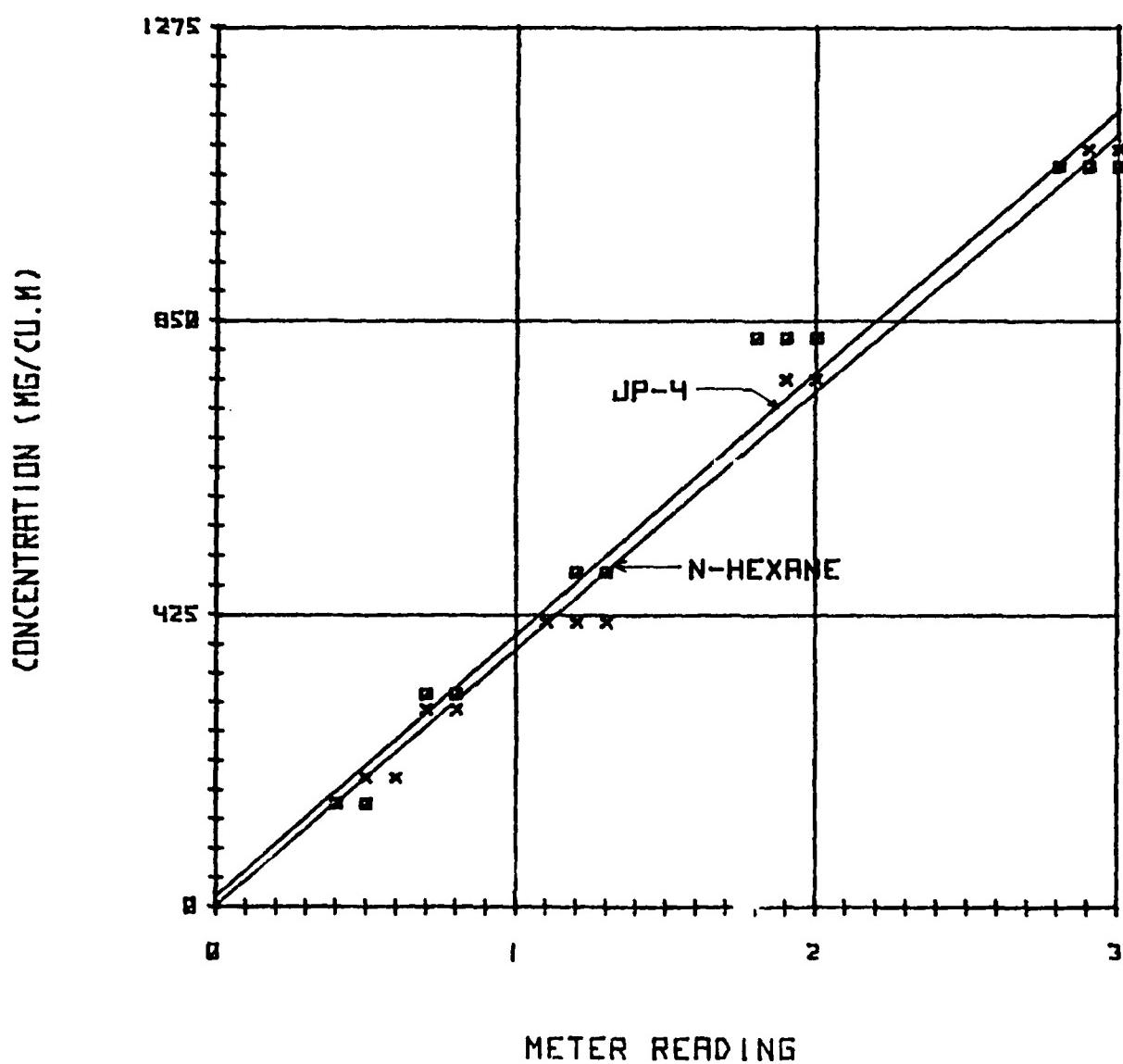
FIGURE. 14. VAPOTESTER RESPONSE TO N-HEXANE & JP-4 VAPOR

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d. General performance

The meter is fully portable and is designed as a vapor checker, not a continuous monitor. It is intended to be operated with disposable alkaline or carbon-zinc batteries. The meter is easy to operate and all controls and adjustments are easily accessible. The stability of the zero setting was poor and the instrument required zeroing each time a sample was taken. The method used to set the zero position was difficult and many squeezings of the aspirator bulb were required to attain a stable reading. To insure proper operation, the meter should be checked for leaks each day before putting it into use. The main drawback of the instrument is the problem in setting the zero where fresh air is not available, as in sampling in confined spaces.

6. GasTechtor

a. Response to n-hexane

The response of the instrument to n-hexane was determined. The results are shown in Table A-XVI and graphically presented in Figure 19A and 19B. The equations of the best-fit lines for these data are shown below:

For 0-500 ppm scale: $Y_1 = 1.13X_1 - 11.1$ $r^2 = 0.996$
    0-100% LEL scale: $Y_2 = 1.09X_2 - 0.860$ $r^2 = 0.998$

Where Y_1 = n-hexane concentration in ppm
      Y_2 = n-hexane concentration in % LEL
      X_1 = meter reading on the 0-500 scale
      X_2 = meter reading on the 0-100% LEL scale

The linearity of response to n-hexane was excellent for both the scales. The calibration stability of the instrument was rechecked in six weeks and was good. The slopes of the least-squares lines changed by 10% on the 0-500 scale and 5% on the 0-100% LEL scale during this period.

b. Linearity of response to acetone

The instrument was calibrated for toluene by the manufacturer and response curves for acetone and methy ethyl ketone (MEK) were provided. The linearity of response to acetone on the 0-500 ppm and the 0-100% LEL scales were checked and the test results are shown in Table A-XV. The equations of the best-fit lines for the 0-500 ppm and 0-100% LEL scales are shown below:

For 0-500 ppm scale: $Y_1 = 1.63X_1 - 28.1$ $r^2 = 0.997$
    0-100% LEL scale: $Y_2 = 0.821X_2 - 1.17$ $r^2 = 0.999$

Where Y_1 = acetone concentration in ppm
      Y_2 = acetone concentration in % LEL
      X_1 = meter reading at 0-500 scale
      X_2 = meter reading at 0-100% LEL scale
      r^2 = correlation coefficient

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GASTECHTOR

SCALE:0-500

METHOD OF VAPOR GENERATION:STATIC

N-HEXANE:X ACETONE(LAB):0 ACETONE(FACT):*
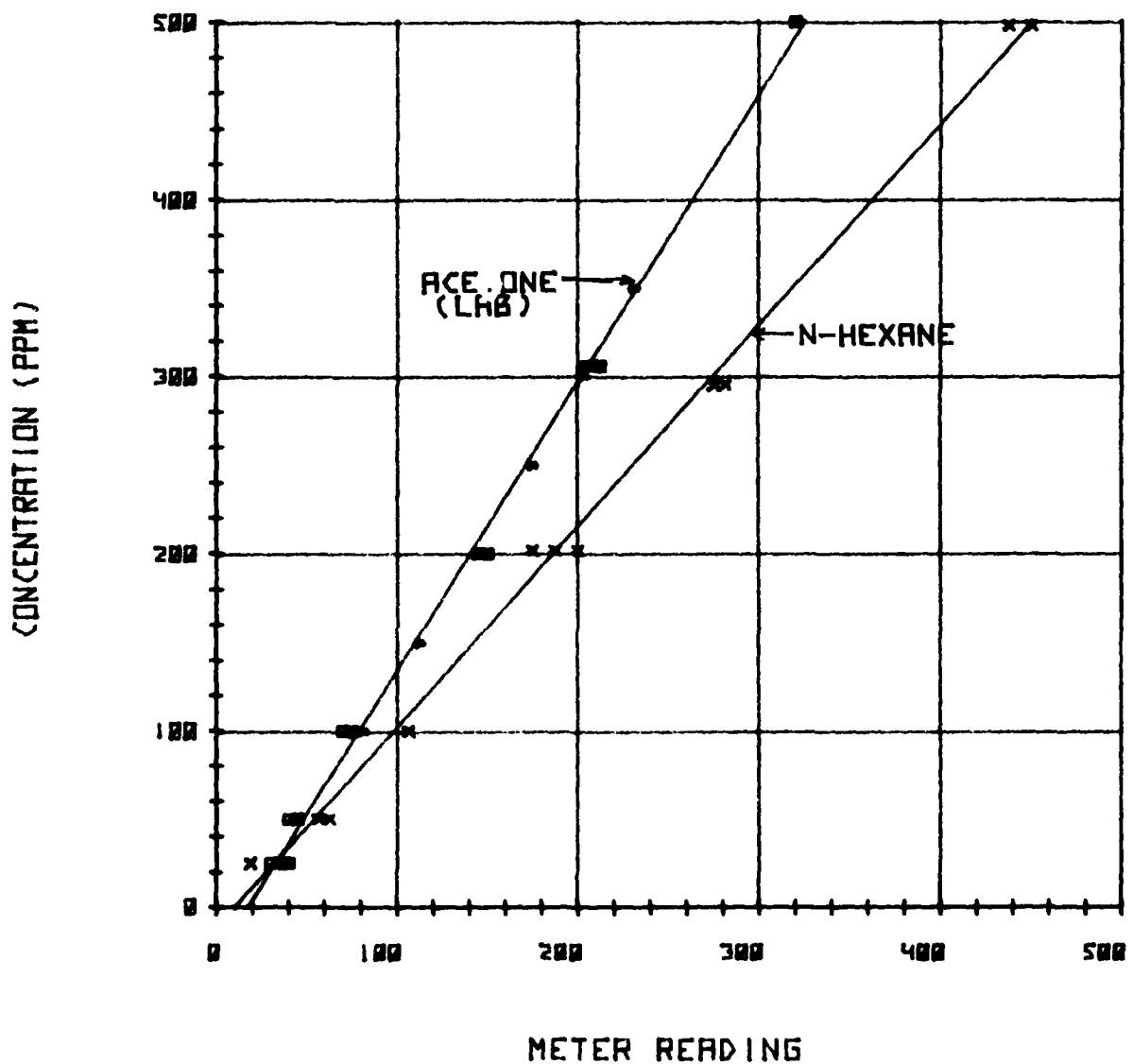
FIGURE 19A. GASTECHTOR RESPONSE TO ACETONE & N-HEXANE

GASTECHTOR

SCALE:0-100%LEL

METHOD OF VAPOR GENERATION:STATIC

N-HEXANE:X ACETONE(LAB):0 ACETONE(FACT):*
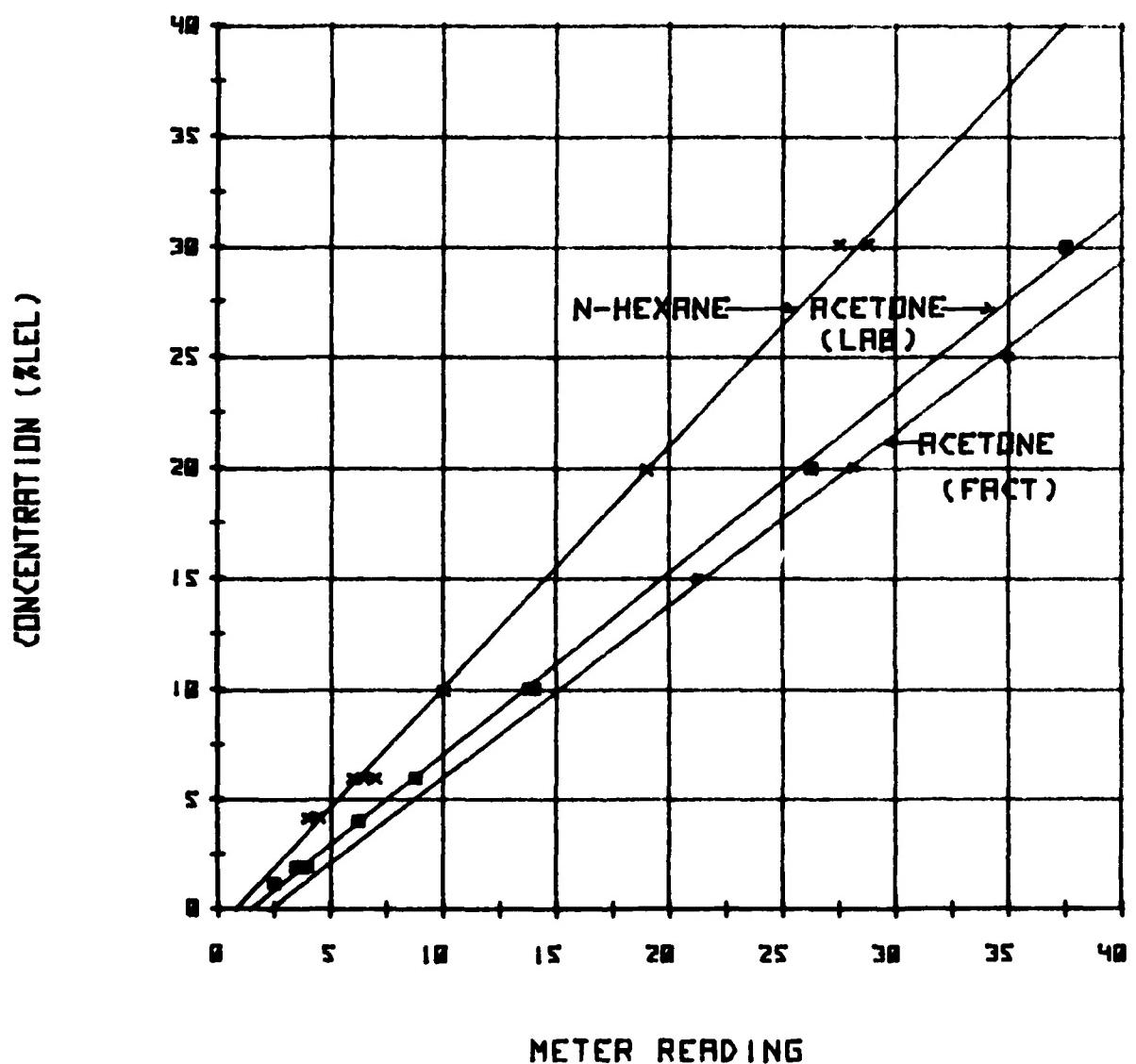
FIGURE 19B. GASTECHTOR RESPONSE TO ACETONE & N-HEXANE

The linearity of response to acetone was good for both scales. When comparing these results with the factory calibration, the instrument's response was changed by approximately 5% on the 0-500 ppm scale and 10% on the 0-100% LEL scale.

c. Response to JP-4 vapor

The response to JP-4 vapors was determined and the test results are shown in Table A-XVII in mg/m^3 (as n-hexane) units. The responses to JP-4 vapor and n-hexane on the 0-500 ppm scale, generated by the dynamic method, scale are shown in Figure 20. The equations of the best-fit lines for n-hexane and JP-4, using gas chromatographic analysis to determine chamber concentration, are shown below:

$$Y_1 = 2.91X - 32.3 \qquad r^2 = 0.998$$
$$Y_2 = 2.89X + 1.63 \qquad r^2 = 0.995$$

Where Y_1 = n-hexane concentration in mg/m^3
Y_2 = JP-4 vapor concentration in mg/m^3 (as n-hexane)
X = meter reading in ppm scale

The meter respone to JP-4 vapor on the 0-500 ppm scale is fairly linear and similar to the response to n-hexane. Therefore, the relative response curve to n-hexane will provide a good indication of the actual JP-4 vapor concentration in terms of mg/m^3 as n-hexane.

d. General performance

The general performance of the meter was excellent. The meter is fully portable and can be operated from a rechargeable battery for approximately 8 hours. It is easy to operate and all controls and adjustments are easily accessible. The span and zero adjustments are independent and easy to use. An audible alarm, active in both combustible ranges and in the oxygen range, sounds whenever gas concentration reaches a pre-set level, and an audible signal is also given in case of malfunctions or a dead battery.

The meter response to dry air (low relative humidity) was significant on the ppm scale. However, its response to known concentrations did not change when the zero adjustment was made under the test conditions of the sample. The manufacturer's calibration of oxygen was checked. When exposed to a known concentration of gas containing 2.5% methane and 17% oxygen in nitrogen, the meter responded precisely. Other observed performance criteria are tabulated in section V.

7. Gas Detector

The manufacturer has calibrated the instrument at two points: 100 ppm hexane for the lower range and 5% LEL hexane for the upper range. A single scale, equally divided into 25 divisions, is used for both ranges. Due to the instrument's logarithmic readout, any concentration reading observed below the 100 ppm point on the lower range or the 5% LEL point on the upper range is difficult to interpret. However, a calibration curve can

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GASTECHTOR

SCALE:0-500

METHOD OF VAPOR GENERATION:DYNAMIC

N-HEXANE:X   JP-4 VAPOR:0
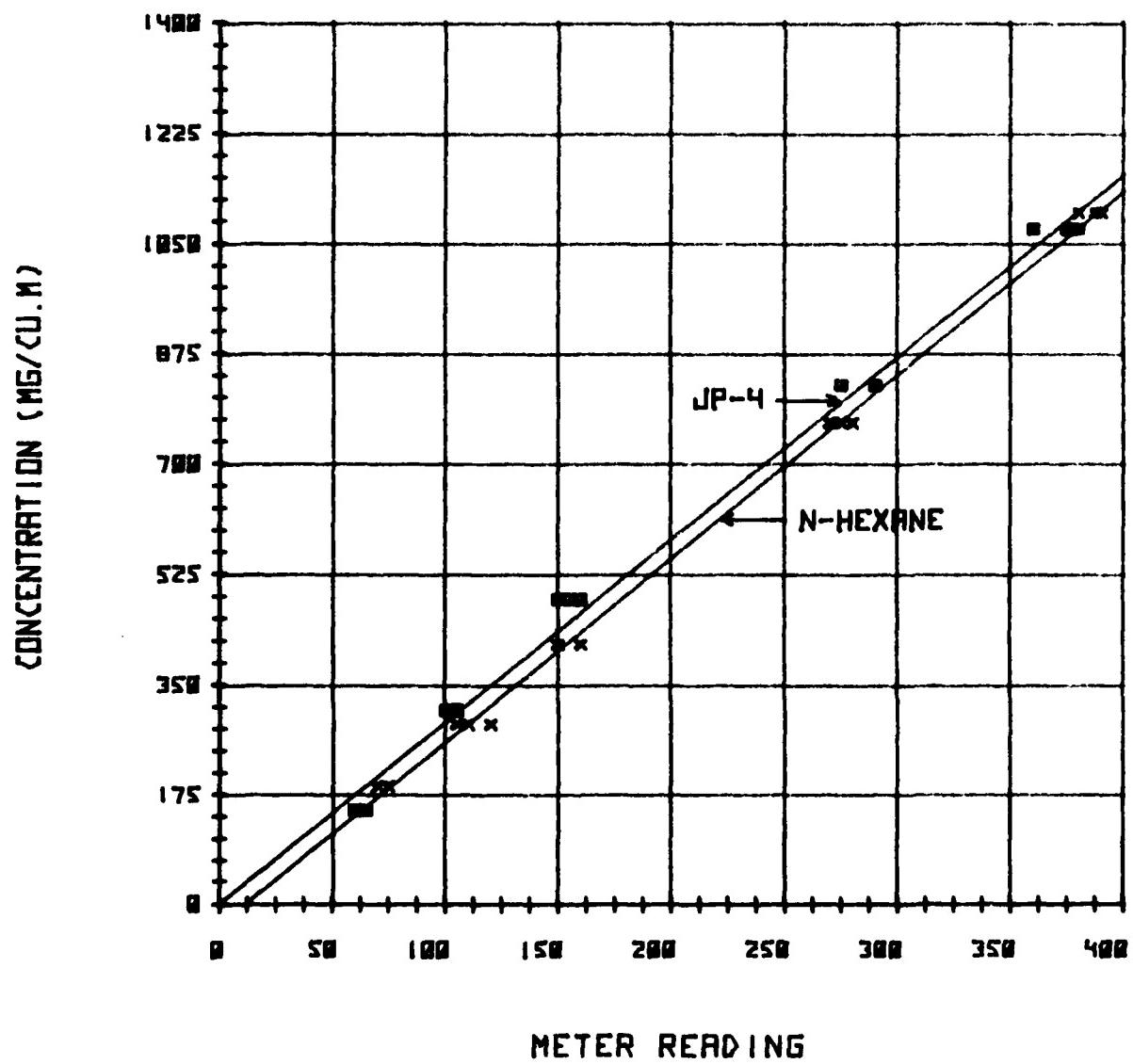
FIGURE 20. GASTECHTOR RESPONSE TO N-HEXANE & JP-4 VAPOR

be constructed and used with the observed meter reading to determine an accurate concentration level of n-hexane.

a. Response to n-hexane

The manufacturer's calibration points on the two ranges were checked and a response curve for n-hexane was constructed. For evaluation purposes, each division on the instrument's scale was reported as 0.2 with the entire scale as 0 to 5. The test results are shown in Table A-XVIII and graphically presented in Figure 21. A sample of 100 ppm n-hexane prepared with clean, dry, house compressed air read 2.4 as opposed to the 5.0 reading calibrated by the manufacturer for the low range. On the high range, 5% LEL n-hexane read 3.2 as opposed to 5.0 reported by the manufacturer.

The calibration stability of the instrument on the lower range was rechecked in three weeks and was poor. The meter reading for 100 ppm n-hexane was 1.2 compared to 2.4 three weeks earlier.

b. Response to JP-4 vapor

The response to JP-4 vapor was determined and the results are shown in Table A-XIX. The responses to JP-4 vapor and n-hexane on the low range, generated by the dynamic method, are shown in Figure 22. The instrument's response to JP-4 vapor was poor and the response curve to n-hexane will not provide a reasonable estimate of the actual JP-4 vapor concentration in terms of mg/m^3 (as n-hexane).

c. General performance

The instrument is fully portable (weighs only $1-^1/_2$ lb) and is very easy to operate. It is designed to clip to a worker's belt and to operate from a rechargeable battery. A visual and audible alarm can be pre-set to the desired level. The meter does not have any capability for zero adjustment and the needle position stayed below the scale readout during the operation mode. The minimum detection limit for n-hexane was 40 ppm. The effect of humidity was checked. A sample of 100 ppm n-hexane prepared with dry house compressed air read 2.4 as opposed to a 3.8 reading with clean, undried compressed air. The other observed performance criteria are tabulated in section V.

8. Combustible Gas/O$_2$ Detector

The meter was factory calibrated to 0-40% O$_2$, 0-4% methane and 0-100% LEL hexane. The factory calibration was checked with a calibration gas containing 2.5% methane and 17% O$_2$ in nitrogen. The meter response to calibration gas was between 2.0 and 2.5 % on the 0-4% methane scale, and 17.0 for the O$_2$ scale. Due to poor sensitivity below 5% LEL, this meter was not completely evaluated because it is not suitable for the application of interest.

a. Response to n-hexane

The manufacturer's calibration of n-hexane on the 0-100% LEL scale was checked. The test results are shown in Table A-XX and graphically

GAS DETECTOR

SCALE:TOXIC POSITION(100 PPM)

METHOD OF VAPOR GENERATION:STATIC
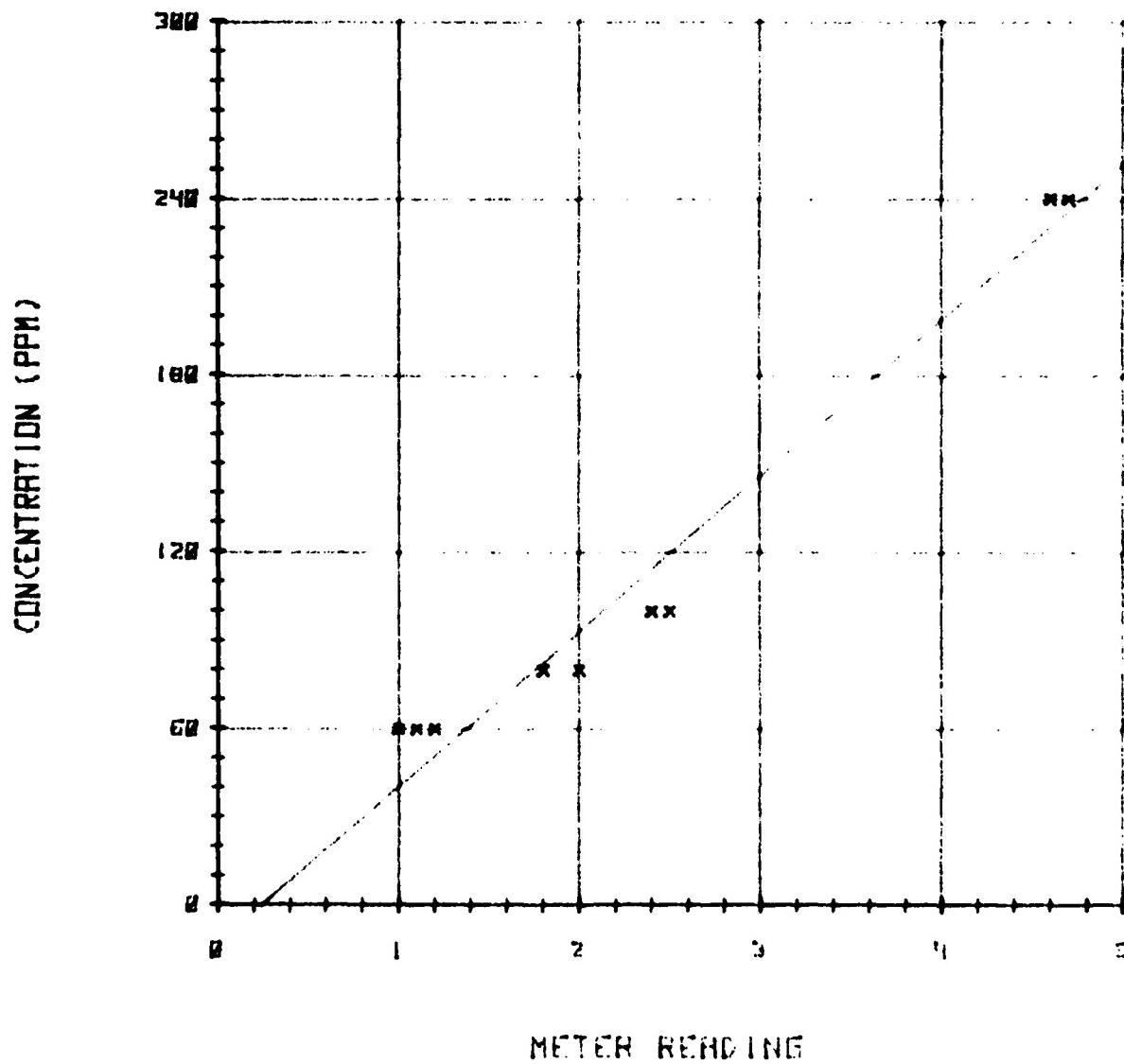
N-HEXANE:X

FIGURE 21. GAS DETECTOR RESPONSE TO N-HEXANE

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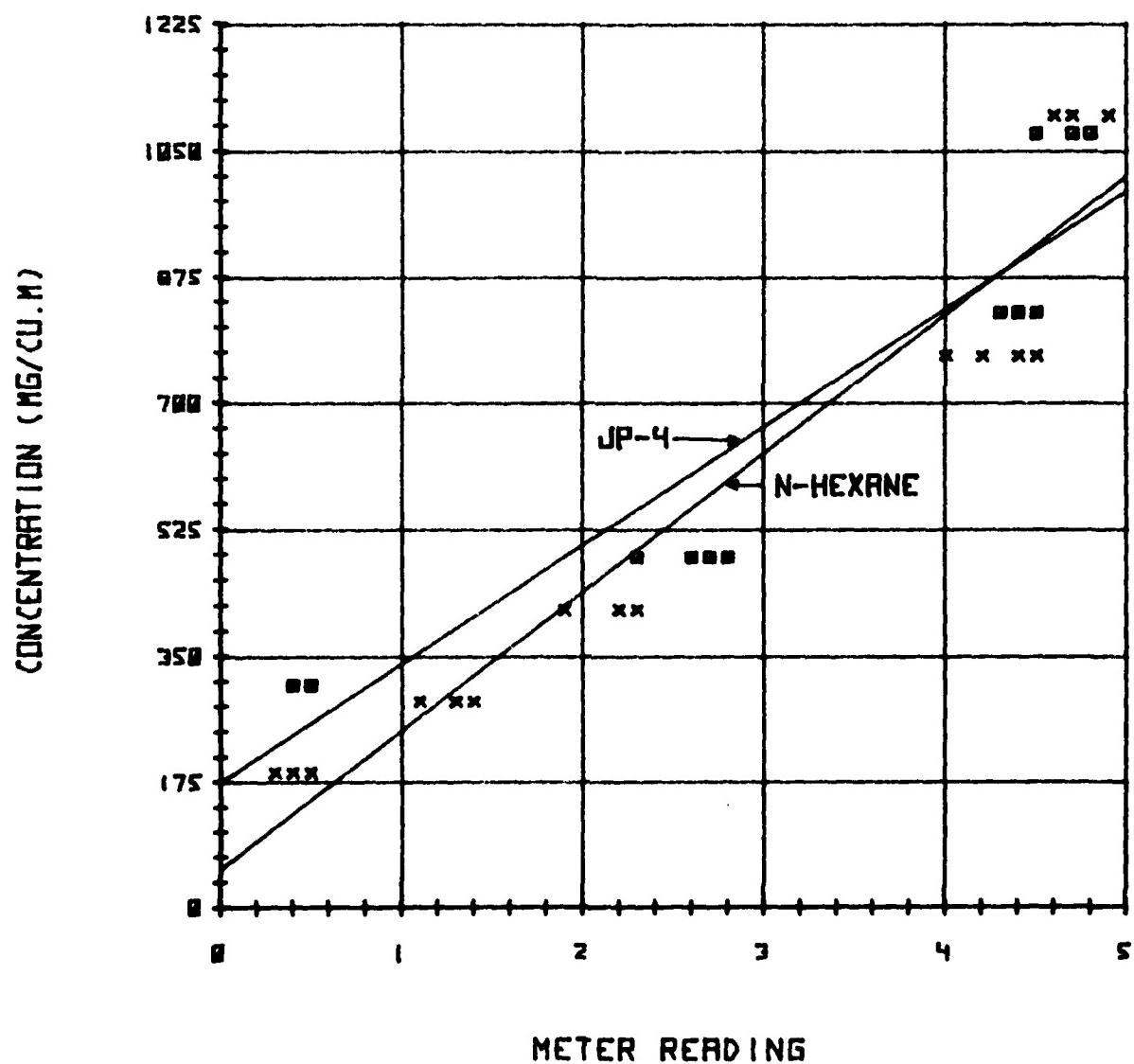
FIGURE 22. GAS DETECTOR RESPONSE TO N-HEXANE & JP-4 VAPOR

presented in Figure 23. The equation of the line which best fits the data are shown below:

$$Y = 1.01X+1.29 \qquad r^2 = 0.985$$

Where Y = n-hexane concentration in %LEL
     X = meter reading
     r^2 = correlation coefficient

b. General performance

The meter can be used for spot checking or as a continuous monitor with alarms. In the continuous mode, the combustible gas level is checked automatically every three minutes. However, the time between samples can be adjusted. It is fully portable with an internal rechargeable battery and can be clipped on a worker's belt. All the adjustments and controls are easily accessible and easy to operate. The manufacturer's alarm set points were determined to be below 19.5% O_2 and at or above 40% LEL.

V. SUMMARY OF RESULTS

The performance characteristics of the meters evaluated are tabulated in this section.

A. Linearity

The results of least-squares fits are tabulated in Table IV. In each case, the slope, intercept, and correlation coefficient (r^2) of a linear regression (L.R.) line are given.

Table IV

Linearity

Meter	Scale	Gas/ Vapor	Slope of L.R. Line	Intercept of L.R. Line	Correlation Coefficient (r^2)
TLV	0-100	n-Hexane (ppm)	1.09	-3.94	0.999
	0-1000	"	1.11	-9.38	0.999
HNU	0-200	"	1.02	-4.34	0.999
	0-2000	"	1.43	-123.0	0.981
OVA-128	0-100	"	1.01	-2.41	0.999

(Continued)

Table IV

Linearity

Meter	Scale	Gas/Vapor	Slope of L.R. Line	Intercept of L.R. Line	Correlation Coefficient (r^2)
	0-1000	"	0.705	46.7	0.999
IR-711	0-100	Propane (% LEL)	0.914	1.55	0.997
	0-100	n-Hexane (% LEL)	0.934	0.274	0.996
Vapotester	0-10	n-Hexane (% LEL)	1.17	0.007	0.999
	0-100	"	1.25	-0.193	0.999
	0-10	Acetone (% LEL)	1.01	-0.085	0.999
	0-100	"	0.951	-0.019	0.999
GasTechtor	0-500	n-Hexane (ppm)	1.13	-11.1	0.996
	0-100	n-Hexane (% LEL)	1.09	- 0.860	0.998
	0-500	Acetone (ppm)	1.63	-28.1	0.997
	0-100	Acetone (% LEL)	0.821	-1.17	0.999
Combustible Gas/ O_2 Detector	0-100	n-Hexane (% LEL)	1.01	1.29	0.985

COMBUSTIBLE/OXYGEN DETECTOR
SCALE:0-100%LEL
METHOD OF VAPOR GENERATION:STATIC
N-HEXANE:X
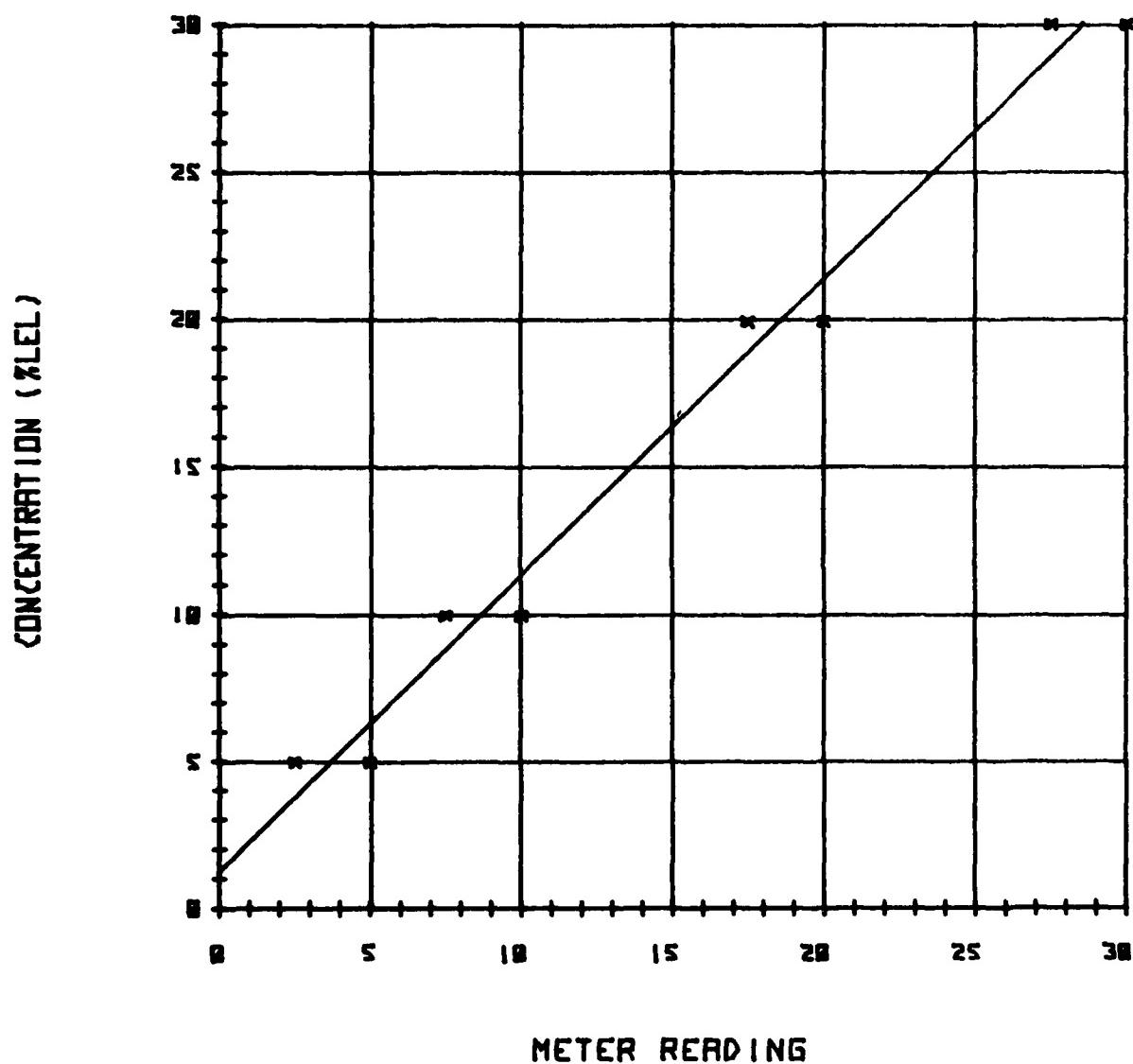
FIGURE 23. COMBUSTIBLE/OXYGEN DETECTOR RESPONSE TO N-HEXANE

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B. Calibration Stability

The calibration stabilities of the meters evaluated are tabulated in Table V.

Table V

Calibration Stability

Meter	Scale	Gas/ Vapor	Change in Slope of L.R. Line	Period between Measurements	Comments
TLV	0-1000	n-Hexane (ppm)	2%	3 weeks	- - -
HNU	0-200	"	22%	3 weeks	Significant changes in gain setting
OVA-128	0-1000	"	5%	3 weeks	- - -
IR-711	0-100	Propane and n-Hexane (% LEL)	2%	2 weeks	- - -
Vapotester	0-10	n-Hexane (% LEL)	13%	6 weeks	- - -
	0-100	"	4%	6 weeks	- - -
GasTechtor	0-500	n-Hexane (ppm)	10%	6 weeks	- - -
	0-100	n-Hexane (% LEL)	5%	6 weeks	- - -
Gas Detector	Toxic (100)	n-Hexane (ppm)	-	3 weeks	Significant change in scale reading for 100 ppm n-hexane (from 2.4 to 1.2 on the scale readout)

C. Response to JP-4 vapor and n-hexane:

The response to JP-4 vapor and n-hexane, generated by the dynamic method are tabulated in Table VI.

Table VI

Meter Response to JP-4 Vapor and n-Hexane

Meter	Scale	Least Squares Line for n-hexane	Least Squares Line for JP-4 Vapor
TLV	0-1,000 ppm	$Y_1 = 4.11X - 176.6$	$Y_2 = 4.18X - 210.6$
HNU	0-2,000 "	$Y_1 = 5.54X - 245.0$	$Y_2 = 2.30X - 69.2$
OVA-128	0-1,000 "	$Y_1 = 2.28X + 77.3$	$Y_2 = 2.45X + 52.6$
IR-711	0-1,000 ppm	$Y_1 = 5.81X + 9.36$	$Y_2 = 5.63X - 222.0$
Vapotester	0-10% LEL	$Y_1 = 373X + 2.79$	$Y_3 = 379X + 17.1$
GasTechtor	0-500 ppm	$Y_1 = 2.91X - 32.3$	$Y_3 = 2.89X + 1.63$

Note: Y_1 = n-hexane concentration in mg/m^3
Y_2 = JP-4 vapor concentration in mg/m^3
Y_3 = JP-4 vapor concentration in mg/m^3 as n-hexane
X = meter reading

D. Response Times

Table VII is a tabulation of response times observed during the evaluation of the meters.

E. Warm-up time

The warm-up times presented in Table VIII include the warm-up period recommended by the manufacturer and a period observed to be adequate for most purposes during these evaluations.

Table VII

Response Times

Meter	Time (sec) to Reach % of Full Response			Time (sec) to go from 100% Response to 0
	90%	95%	100%	
TLV	38	45	90	58
HNU	7	12	19	30
OVA-128	25	–	40	25
IR-711	10	–	29	20
Vapotester	15	–	20	–
GasTechtor	–	15	20	–
Gas Detector	45	–	75	–
Combustible gas/				
O$_2$ Detector	45	–	70 (for combustible gas)	–
	16	–	35 (for oxygen)	–

Table VIII

Warm-up Time

Meter	Warm-up Time (Observed to be Adequate for most Purposes)	Warm-up Time (Recommended by the Manufacturer)
TLV	30 min	10 min
HNU	None required	–
OVA-128	5-10 min	5 min
IR-711	25-30 min	5 min (minimum)
Vapotester	None required	–
GasTechtor	5-10 min	5 min
Gas Detector	20-30 min	30
Combustible Gas/		
O$_2$ Detector	5	–

VI. RECOMMENDATIONS

Because there are a variety of commercially available instruments for the measurement of combustible gases, the selection of any device will depend upon how well it meets the requirements of a particular situation. The other features to be considered in selecting such a device are its portability, sensitivity, reliability, and intrinsic safety. Combustible gas meters are not all intrinsically safe. Although some manufacturers certified their own instruments as intrinsically safe, certification by an independent organization (such as MESA, MSHA, FM, UL, CSA etc.), is required by the USAF OEHL before a meter is used in possibly explosive environments. Another feature to be considered is the capability to detect oxygen-deficient atmospheres for use in confined spaces, such as during fuel cell maintenance operations (T.O. 1-1-3). Although two separate instruments can be used to serve this purpose, an instrument with both capabilities is desirable. A summary of the evaluation of each instrument is discussed below to aid in the selection of an instrument based on the application of interest.

The objective of this evaluation was to select a direct-reading instrument for measuring combustible gases and fuel vapors (such as JP-4 and JP-5) for general use and specifically for use in aircraft fuel cells. The selected instrument must be capable of measuring both the fire safe limit (20% LEL) and levels of health consequence (below 5% LEL).

Of the meters tested, GasTech, Inc's GasTechtor, Model 1314, is one of two instruments which have the capability to detect both combustible gases and oxygen deficiencies. However, the GasTechtor has not been certified intrinsically safe by an independent laboratory. The GasTechtor has excellent response sensitivity for combustible gases and JP-4 vapors. The instrument's lower level of sensitivity for JP-4 vapor is 100 mg/m³ as n-hexane with an error limit of 7.5% of reading. The instrument is very easy to use and the overall performance is excellent. The GasTechtor is probably the most suitable for fuel cell maintenance operation, after a certificate of intrinsic safety has been awarded by an independent laboratory.

The TLV Sniffer has excellent response sensitivity for combustible gases and JP-4 vapors and the responses to all gases and vapors were similar over the range tested. The TLV Sniffer is able to detect JP-4 vapors at a lower concentration level of 100 mg/m³ within an error limit of 15% of the reading. The TLV Sniffer can be used for fuel cell maintenance operations, but a separate oxygen-deficiency meter will be needed to detect oxygen-deficient atmospheres as specified in T.O. 1-1-3. The cost of the instrument is approximately the same as GasTechtor.

The performance of the Organic Vapor Analyzer, OVA-128, is also very good. Its response to JP-4 vapors is good and of all the instruments evaluated, the OVA-128 is the only one with a capability for qualitative analysis to separate and quantify the various components in mixtures which are common in industrial workplaces. The requirement for a fuel (hydrogen) supply for the flame ionization detector is a major drawback for its use as a general purpose instrument and the OVA 128 is much more expensive than the TLV Sniffer and GasTechtor.

The measured performance of the HNU Photoionizer, with the 10.2 eV lamp, is fair for low concentrations of n-hexane. However, it is not suitable for application to JP-4 vapor due to its poor response at low concentrations. The instrument is best suited to detect very low concentrations of specific molecules with ionization potentials less than the photon energy of the UV source (10.2 eV). The instrument is well suited for the detection of aromatic organic vapors, but it can also be used to detect some inorganic gases including hydrogen sulfide and ammonia. The cost of this instrument is also much higher than that of the TLV Sniffer and the GasTechtor.

The Infrared Industries, Inc's Hydrocarbon Analyzer, Model IR-711 was not completely evaluated. Its response to hexane and JP-4 vapors, on the low scale, factory calibrated for 0-1,000 ppm JP-5, is poor. However, the response to JP-5 vapors was not thoroughly checked due to difficulty in generating known JP-5 concentrations. The major drawback of this instrument is the fixed calibration of the ppm scale. The measured performance for the high scale (calibrated for 0-100% LEL) is excellent, and this is the only instrument to respond the same for both propane and n-hexane. Its response to aromatic hydrocarbons (as toluene) is lower. The IR-711 can be best used to measure the percent LEL of hydrocarbon fuels if the percent of aromatic compounds present in the vapor is negligible. However, it is not suitable for the application of interest because the 15 cm optical path is too short to provide the sensitivity needed for measurements below 5% LEL. It is also lacking a certificate of intrinsic safety.

The Scott Aviation's Vapotester, Model D-16 has good response sensitivity to combustible gases and to JP-4 vapors. The lower limit of detection is 0.4% LEL JP-4 vapors as n-hexane with an error limit of 20% of the reading. The responses to all tested gases and vapors are similar over the range. The instrument is designed as a spot checker, not a continuous monitor. The meter's requirement for zeroing before each sample will cause problems where uncontaminated air is not available.

The Enmet Gas Detector, Model CGS-8LM response to n-hexane is fair. However, due to the logarithmic readout, it is difficult to interpret how a true concentration corresponds to an observed scale reading other than at its single marked point on each scale. The calibration stability with time is poor. The meter is not suitable for the application of interest because its response to JP-4 vapor is poor.

The Bio Marines Combustible Gas/O_2 Detector, Model 900 is not suitable for the application of interest due to its poor sensitivity below 5% LEL.

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APPENDIX A

EXPERIMENTAL DATA AND TABLES

Table A-I

TLV Sniffer Calibration Data for n-Hexane
Method of Vapor Generation: Static

Meter Reading	n-Hexane Concentration	
	ppm	mg/m²
Scale: 0-100		
21	19	67
37	37	131
48	47	166
89	93	329
Scale: 0-1000		
65	67	237
130-135	131	461
260	280	989
430	467	1648
Scale: 0-10,000		
1015	1005	3548
1750	2010	7095
2100	2338	8253
3200	3741	13206
*Scale: 0-1000		
40	37	131
50	47	166
105	93	329
145	140	495
190	187	661
275	280	990
695	746	2639

*Meter reading rechecked (about three weeks after calibration)

Table A-II

TLV Sniffer Response to Propane

Method of Vapor Generation: Static

TLV Scale Reading (0-10,000 scale)	Propane Concentration		Method of Gas Generation
	ppm	mg/m^3	
2025	2494	4507	
4025	4975	8990	Static
6250	7444	13451	
8300	9901	17891	Generation

Table A-III

TLV Sniffer Response To JP-4 Vapors and n-Hexane

Method of Vapor Generation: Dynamic System

Method of Analysis: Gravimetric

Meter Reading	n-hexane Concentration (mg/m^3)	JP-4 Vapor Concentration (mg/m^3)
Scale: 0-1000		–
75	188 (avg of 2 samples)	–
230	681 (avg of 2 samples)	–
500	1912 (avg of 3 samples)	
65	–	120 (avg of 2 samples)
120	–	198 (avg of 2 samples)
230	–	733 (avg of 3 samples)
430	–	1626 (avg of 3 samples)
190	–	525 (avg of 2 samples)
80	–	195 (avg of 2 samples)

Table A-IV

HNU Photoionizer (PI-101) Calibration Data for n-Hexane

Method of Vapor Generation: Static

Meter Reading	n-Hexane Concentration	
	ppm	mg/m³
Scale: 0-200		
23	19	67
42	37	131
49	47	166
94	93	329
142	140	495
Scale: 0-2000		
140	140	495
190	187	661
280	280	990
520	746	2639
*Scale: 0-200		
29	19	67
57	37	131
62	47	166
120	93	329
182	140	495

* Meter reading rechecked (about three weeks after calibration)

Table A-V

HNU Photoionizer Response to JP-4 Vapor and n-Hexane

Method of Vapor Generation: Dynamic System

Method of Analysis: Gravimetric

Meter Reading	n-Hexane Concentration (mg/m³)	JP-4 Vapor (mg/m³)
Scale: 0-2000		
60	188 (avg of 2 sample)	-
20	681 (avg of 2 sample)	-
375	1912 (avg of 3 sample)	-
380	-	733 (avg of 3 samples)
90	-	195 (avg of 2 samples)
270	-	525 (avg of 2 samples)
720	-	1626 (avg of 3 samples)

Table A-VI

OVA-128 Calibration Data for n-Hexane

Method of Vapor Generation: Static

Meter Reading	n-Hexane Concentration	
	ppm	mg/m³
Scale: 0-100		
70	67	237
21	19	67
39	37	131
49	47	166
94	93	329
Scale: 0-1000		
130	131	461
320	280	990
585	467	1648
140	140	495
195	187	661
330	280	990
1000	746	2633
*Scale: 0-1000		
130	140	495
180	187	661
310	280	990
940	746	2633

* Meter reading rechecked (about three weeks after calibration)

Table A-VII

OVA-128 Response to JP-4 Vapors and n-Hexane

Method of Vapor Generation: Dynamic System

Method of Analysis: Gravimetric

Meter Reading	n-Hexance Concentration (mg/m^3)	JP-4 Vapor Concentration (mg/m^3)
Scale: 0-1000		
60	188 (avg of 2 samples)	
250	681 (avg of 2 samples)	
810	1912 (avg of 3 samples)	
50	—	195 (avg of 2 samples)
180	—	525 (avg of 2 samples)
310	—	733 (avg of 3 samples)
630	—	1626 (avg of 3 samples)

Table A-VIII

IR-711 Response To JP-5 Vapors

Method of Vapor Generation: Dynamic Generation System

Method of Analysis: Gravimetric

IR-711 Reading (0-1000 scale)	JP-5 Vapor Concentration mg/m³	ppm
50 ± 25	375	54
125 ± 25	1248	180
	1469	212

Table A-IX

IR-711 Response to Propane

Method of Gas Generation: Static Generation System

IR-711 Reading (0-100% LEL Scale)	Propane Concentration ppm	% LEL
11.8 ± 1.0	2494	11.6
22.8 ± 0.5	4975	23.1
35.5 ± 0.8	7444	34.6
49.4 ± 0.4	9901	46.1

Table A-X

IR-711 Response to n-Hexane and JP-4 Vapors

Method of Vapor Generation: Dynamic Generation System

Method of Analysis: Gravimetric

IR-711 Reading (0-1000 ppm scale)	n-Hexane Concentration (mg/m³)	JP-4 Vapor Concentration (mg/m³)
400-450	2482	–
85-90	669	–
70-75	275	–
40-60	–	116
80-85	–	190
140-150	–	606
300-325	–	1227
325-350	–	1970

Table A-XI

IR-711 Response to n-Hexane and Toluene on 0-100 % LEL Scale

Method of Vapor Generation: Static

IR-711 Reading	n-Hexane Concentration		Toluene Concentration	
	ppm	% LEL*	ppm	% LEL**
8.75	1028	8.6	–	–
16.25	1942	16.2	–	–
22.5	2378	19.8	–	–
32.5	3747	31.2	–	–
47.5	5364	44.7	–	–
2.5-3.75	–	–	911	7.6
2.5-5.0	–	–	1039	8.7
5.0-6.25	–	–	1937	16.1
6.25-7.5	–	–	2065	17.2
8.75-11.25	–	–	2449	20.4
12.5-13.75	–	–	2578	21.5

* % LEL for n-Hexane: 100 % LEL = 1.2×10^4 ppm
** % LEL for Toluene: 100 % LEL = 1.2×10^4 ppm

Table A-XII

Vapotester Calibration Data for n-Hexane

Method of Vapor Generation: Static

Meter Reading	n-Hexane Concentration ppm	% LEL
Scale: 0-10% LEL		
0.4, 0.4, 0.4	60	0.50
0.8, 0.9, 0.9, 0.8	120	1.00
1.8, 1.7, 1.6	243	2.02
6.2, 6.2, 6.0	840	7.00
8.5, 8.4. 8.3	1194	9.95
Scale: 0-100% LEL		
1.5, 1.5, 1.5 (>1.0 <2.0)	202	1.68
2.0, 2.0, 2.0	295	2.46
3.5, 3.5, 3.5 (>3.0 <4.0)	498	4.15
5.0, 5.0, 5.0	715	5.96
8.5 (>8.0 <9.0), 8.0, 8.0	1194	9.95
17.0, 16.0, 16.0	2389	19.9
24.5 (>24.0 <25.0), 24.0, 24.0	3608	30.1
*Scale 0-10% LEL		
0.5, 0.6, 0.5	61	0.51
0.9, 0.9, 0.9	121	1.01
1.6, 1.6, 1.6	243	2.02
2.5, 2.4, 2.5	364	3.03
4.0, 3.9, 3.8	597	4.98
7.8, 7.7, 7.5	1200	10.00
*Scale 0-100% LEL		
4.5, 4.5, 4.5 (>4.0 <5.0)	597	4.98
8.5 (>8.0 <9.0), 8.0, 8.0	1200	10.0
17.5 (>17.0 <18.0, 17.0, 17.0	2407	20.1
24.C, 23.0, 23.0	3608	30.1

*Meter reading rechecked (about six weeks after calibration).

Table A-XIII

Vapotester Response to Acetone

Method of Vapor Generation: Static Generation System

Meter Reading	Acetone Concentration	
	ppm	% LEL
Scale: 0-10% LEL		
0.4, 0.4, 0.4	100	0.385
0.8, 0.9, 0.9	200	0.770
1.2, 1.2, 1.2	306	1.18
2.0, 1.95, 1.95	500	1.93
4.1, 4.2, 4.2	1040	4.00
6.0, 6.0, 6.1	1552	5.97
9.9, 9.8, 9.9	2006	10.0
Scale: 0-100% LEL		
1.5, 1.5, 1.0	306	1.18
2.0, 2.0, 2.0	500	1.93
4.5, 4.5, 4.5	1040	4.00
6.5, 6.0, 6.5	1552	5.97
10.5, 10.0, 10.0	2006	10.02
21.0, 21.0, 21.0	5193	19.97
32.0, 31.5, 31.5	7800	30.0

Table A-XIV

Vapotester Response to JP-4 Vapor and n-Hexane

Method of Vapor Generation: Dynamic Generation System

Method of Analysis: Gas Chromatographic

Meter Reading	JP-4 Vapor Concentration (mg/m^3 as n-Hexane)	n-Hexane Concentration (mg/m^3)
Scale: 0-10% LEL		
2.9, 2.9, 3.0, 2.8	1074±25.8	–
2.0, 1.9, 1.8, 2.0	825±22.5	–
1.2, 1.3, 1.2, 1.3	486±4.36	–
0.8, 0.7, 0.7, 0.8	310±7.21	–
0.5, 0.4, 0.5, 0.4	150±3.51	–
0.5, 0.5, 0.6, 0.5	–	188±5.8
0.7, 0.7, 0.8, 0.7	–	287±1.5
1.1, 1.2, 1.1, 1.3	–	414±6.7
2.0, 2.0, 1.9, 1.9	–	765±5.5
2.9, 3.0, 3.0, 3.0	–	1099±19.1

Table A-XV

GasTechtor Response to Acetone

Method of Vapor Generation: Static Generation System

Meter Reading	Acetone Concentration	
	ppm	% LEL
Scale: 0-500 ppm		
30 (>25 <37.5), 37.5, 40 (>37.5 <50)	25	0.096
45, 40, 45 (>37.5 <50)	50	0.192
70 (>62.5 <75), 75, 75	100	0.385
145 (>137.5 <150), 150, 150	200	0.770
212, 205 (>200 <212.5), 212	306	1.18
320, 320, 320	500	1.93
Scale: 0-100% LEL		
2.5, 2.5, 2.5	306	1.18
4.0 (>3.75 <5.0), 3.5 (<3.75), 3.75	500	1.93
6.25 (>5.0 <7.5), 6.25, 6.25	1040	4.0
8.75 (>7.5 <10.0), 8.75, 8.75	1552	5.97
13.75 (>12.5 <15.0), 14.0 (>13.75), 14.0	2006	10.02
26.25 (>25.0 <27.5), 26.25, 26.25	5193	19.97
37.5, 37.5, 37.5	7800	30.0

Table A-XVI

GasTechtor Response to n-Hexane

Method of Vapor Generation: Static

Meter Reading	n-Hexane Concentration ppm	% LEL
Scale: 0-500 ppm		
18.75, 18.75, 18.75 (>12.5 <25.0)	25	0.21
56.25, 56.25 (>50.0 <62.5), 62.5	50	0.42
106.25, 106.25, 106.25 (>100 <112.5)	100	0.83
175, 200, 187.5 (>175 <200)	202	1.68
275, 281.25 (>275 <287.5), 275	295	2.46
450, 437.5 (>425 <450), 437.5	498	4.15
Scale: 0-100% LEL		
4.5 (<5.0), 4.0 (>2.5 <5), 4.5 (<5.0)	498	4.15
6.5 (>5.0 <7.5), 7.0 (<7.5), 6.0 (>5.0)	715	5.96
10.0. 10.0, 10.0	1194	9.95
19.0, 19.0, 19.0 (<20.0)	2389	19.9
28.75 (>27.5 <30.0), 28.75, 27.5		
*Scale: 0-500 ppm		
45, 45, 45, (>37.5 <50.0)	61	0.51
110, 110 (>100 <112.5), 105 (>100)	121	1.01
200, 210, 210 (>200 <212.5)	243	2.02
310, (>300 <312.5), 305, 305 (>300)	364	3.03
*Scale: 0-100% LEL		
5.0, 5.0, 5.0	597	4.98
9.5, 9.5, 9.5 (<10.0)	1203	10.0
20.0, 19.5, 19.5 (<20.0)	2407	20.1
27.5, 26.25, (>25 <27.5), 25	3608	30.1

*Meter reading recheck (about six weeks after calibration)

Table A-XVII

GasTechtor Response to JP-4 Vapor and n-Hexane

Method of Vapor Generation: Dynamic Generation

Method of Analysis: Gas Chromatographic

Meter Reading	JP-4 Vapor Conc. (mg/m³ as n-Hexane)	n-Hexane Conc. (mg/m³)
Scale: 0-500 ppm		
360 (>350 <375), 375, 380 (>375), 375	1074±25.8	—
275, 290 (>275 <300), 290, 290	825±22.5	—
150, 160, 160 (>150 <175), 155 (>156)	486±4.356	—
105, 105 (>100), 100, 105	310±7.21	—
60, 60 (>50 <75), 65 >50 <75), 60	150±3.51	—
70 (>62.5 <75.0), 75, 75	—	188±5.8
120 (<125), 105 (>100 <112.5), 110 (<112.5)	—	287±1.5
160 (>150 <162.5), 150, 150	—	414±6.7
275, 270 (<275), 275, 280 (>275)	—	765±5.5
380 (>375 <387.5), 390 (>387.5), 390, 387.5	—	1099±19.1

Table A-XVIII

Gas Detector Calibration Data for n-Hexane

Method of Vapor Generation: Static

Meter Reading	n-Hexane Concentration ppm	% LEL	Method of sample preparation
Scale: Toxic position (100 ppm)			
1.1, 1.0, 1.2	60	0.50	Sample was prepared with clean, dry house compressed air.
1.8, 1.8, 2.0	80	0.67	
2.4, 2.4, 2.5	100	0.83	
4.7, 4.6, 4.6	240	2.0	
Scale: Comb. position (5% LEL)			
1.5, 1.6, 1.7	360	3.0	
3.2, 3.2, 3.4	600	5.0	
3.2, 3.2, 3.2	720	6.0	
4.2, 4.2, 4.3	960	8.0	
Scale: Toxic			
3.6, 3.8, 4.1	100	0.83	Sample was prepared with clean house compressed air (non-dry).
Scale: Comb			
3.6, 3.5, 3.5	600	5.0	
*Scale Toxic			
1.2, 1.2	100	0.83	Sample was prepared with clean house compressed air (non-dry).

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(Continued)

Table A-XVIII

Gas Detector Calibration Data for n-Hexane

Method of Vapor Generation: Static

Meter Reading	n-Hexane Concentration		Method of sample preparation
	ppm	% LEL	
*Scale: Toxic			
1.2, 1.2, 1.3	100	0.83	Sample was prepared with clean house compressed air (non-dry).

*Meter reading rechecked (about three weeks after calibration)

Table A-XIX

Gas Detector Response to JP-4 Vapors and n-Hexane

Method of Vapor Generation: Dynamic Generation System
(Used clean housed compressed air).

Method of Analysis: Gas Chromatographic

Meter Reading	JP-4 Vapor Concentration (mg/m³ as n-Hexane)	n-Hexane Concentration (mg/m³)
Scale: Toxic position (100 ppm)		
4.7, 4.8, 4.8, 4.5	1074±25.8	---
4.3, 4.4, 4.4, 4.5	822±22.5	---
2.6, 2.8, 2.7, 2.3	486±4.36	---
0.5, 0.4, 0.4, 0.5	310±7.21	---
0.3, 0.4, 0.5, 0.5	---	188±5.8
1.3, 1.3, 1.1, 1.4	---	287±1.5
1.9, 2.2, 2.2, 2.3	---	414±6.7
4.0, 4.4, 4.2, 4.5	---	765±5.5
4.6, 4.7, 4.9, 4.9	---	1099±19.1

Table A-XX

Combustible/O_2 Detector Response to n-Hexane

Method of Vapor Generation: Static Generation System

Meter Reading	n-Hexane Concentration ppm	% LEL
Scale: 0-100% LEL		
>2.5 <5.0, >2.5 <5.0	598	4.98
>7.5 <10.0, 10.0	1194	9.95
>17.5 <20.0, 17.5, 17.5	2388	19.9
>27.5 <30.0, >27.5 <30.0, 27.5	3600	30.0